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AN EVALUATION OF A HONDA "ELECTRO GYRO-CATOR" LAND NAVIGATION SYSTEM

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AUGUST 1983

U.S. ARMY MISSILE COMMAND
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A Honda "Electro Gyro-Cator" land navigation system was evaluated under laboratory and field conditions to determine land navigation accuracies. Laboratory evaluations determined system characteristics such as static drift, frequency response, phase shift, and input-output characteristics (scale factor, bias, and hysteresis). Field evaluations determined land navigation accuracies of approximately 3.5% RMS error per distance traveled.

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CONTENTS

I. INTRODUCTION

The Honda "Electro Gyro-Cator" is a land navigation system developed by Honda R&D Co., Ltd. for commercial use in Honda automobiles. The primary elements of the system include a distance indicator, a direction indicator, a 16-bit central processing unit, a CRT display screen and overlay maps sized for the screen. Because they have no influence on the active elements of the system, the display screen and overlay maps were not used.

The operating principles of the system are to detect changes in distance and direction and then to instantaneously integrate the changes. Figure 1 shows the elements of the system. The "mileage sensor", simply a pulse encoder, detects distance traveled by producing eight pulses per odometer cable revolution, which is proportional to tire revolution. The "direction sensor" shown in Figure 2, is a sealed helium gas-rate gyro. The gas is circulated by a piezo-vibrator pump. Twin tungsten heated wires, the sensors, are located in the helium jet flow. When the sensor is stationary or moving straight ahead, the wires are cooled evenly by the gas flow. When the sensor turns about its input axis, the sensing wires move in relation to the previously ejected gas. This movement causes the instantaneous flow of gas to cool one wire more than the other. The change in temperature is detected as a change in power output which is electrically picked up and processed by the CPU. The gyro is therefore extremely susceptible to temperature variations. To remedy this situation, heaters have been designed in the system to maintain a constant temperature of 60°C on all components. Another problem is the error induced by vehicle tilt causing the gas flow to cool one wire more than the other. Honda's remedy for this error is to mount the rate sensor on a "bowl-within-a-bowl" type fixture so the sensor can be leveled. Of course, there is no remedy for errors induced by vehicle tilt due to windage or turns. The navigation computer is a high speed 16-bit microprocessor with an A/D converter.

Position determination is made by processing sensor inputs. The vehicle's present location in a two dimensional system is calculated thusly:

$$X = \int v(t) \cos(\theta)\, dt \qquad (1)$$

$$Y = \int v(t) \sin(\theta)\, dt \qquad (2)$$

Where t is time; v(t) is velocity, and θ is heading.

The heading is:

$$(\theta) = \int w(t)\, dt \qquad (3)$$

Where w(t) is the rate gyro output.

The "Electro Gyro-Cator" is not a stand alone land navigator. It has no self determining north alignment capability nor does it have elevation change determination. The CRT display screen and overlay maps are the designers approach to initialization, traversion display, and error correction.

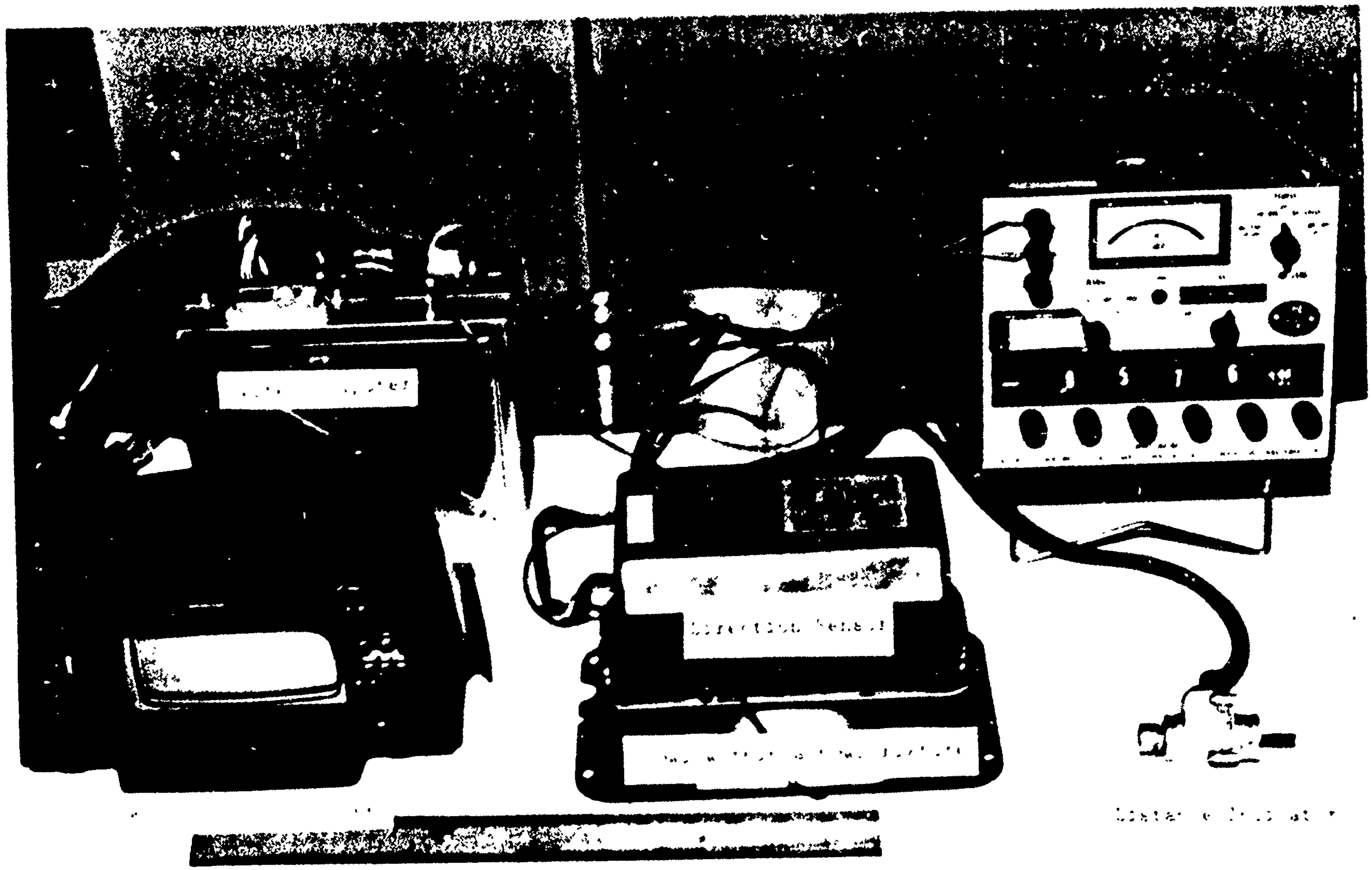


Figure 1. Honda "Electro" Gyro Cator components.

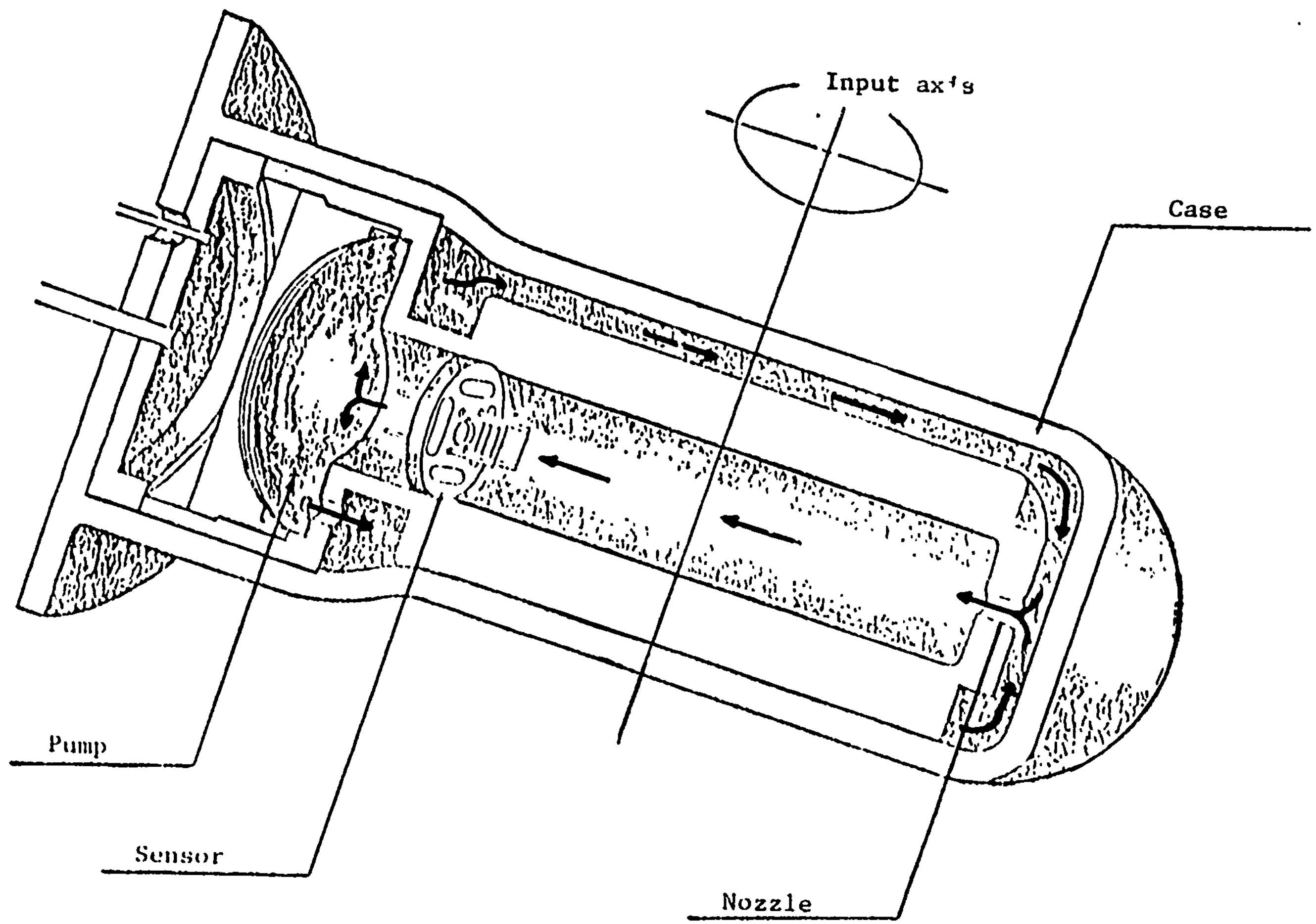


Figure 2. Honda "Electro Gyro-Cater" "directional sensor".

The system incorporates the "zero-velocity update" method of error correction. This method requires the vehicle to come to a complete 15 second stop every 20 minutes. The system checks the "distance sensor" for outputs, if there are none for 15 seconds it knows there is zero velocity. Knowing that the vehicle can not change heading without wheel rotation the update is made. If there are any gyro outputs during the 15 seconds, these are known as errors. This drift error is calculated and taken into account for further computations. During commercial use, for which it was designed, the operator can eliminate these errors by repositioning the cursor on the display screen to known landmarks indicated on the overlay map.

II. OBJECTIVE

The object of this study was to evaluate the land navigation capabilties of a typical off-the-shelf, commercially, not militarily, designed Honda "Electro Gyro-Cator". Evaluation of land navigation capabilities includes determinaion of point-to-point and closed loop accuracies. Gyroscope characteristics were also determined.

III. PROCEDURE

Evaluation of the system consisted of two major efforts. The first of which was the determination of the rate gyro characteristics. This task was accomplished in the Inertial Systems Development Branch's laboratory facility located in Building 5400. The second of the two efforts was the determination of on-the-road land navigation accuracies and characteristics.

Laboratory evaluations consisted of static drift, frequency response, phase shift, and input-output characteristics (scale factor, bias, and hysteresis). The static drift was determined by energizing the unit, waiting the 30 minutes warm-up period, then recording the voltage every 30 minutes for 8 hours. The frequency response and phase shift were determined by placing the unit on a Micro Gee Angular Oscillating Table Model 61A, S/N 7117, and driving the input while monitoring the output with a Model 1410 Schlumberger Frequency Response Analyzer. To distinguish between the response of the Oscillating Table and the response of the gyro, frequency response characteristics of the table were also acquired. The input-output characteristics were determined by placing the unit on a Model C-181 Genesco Rate of Turn Table, S/N 947, (the rate table inputs were monitered by measuring the time per revolution using a HP5330B Preset Counter, S/N 24A00481) and recording the output voltage. The gyro response to input rates was determined at various temperatures (ambient, -30°C, +60°C) for a check of the effect of temperature on the unit.

All voltages for laboratory data acquisition were recorded with a John Fluke DC Differential Voltmeter Model 887AB, S/N 2519. A wiring schematic for power to and output from the gyro is shown in Figure 3.

The raw data from the laboratory evaluations is shown in Appendix A.

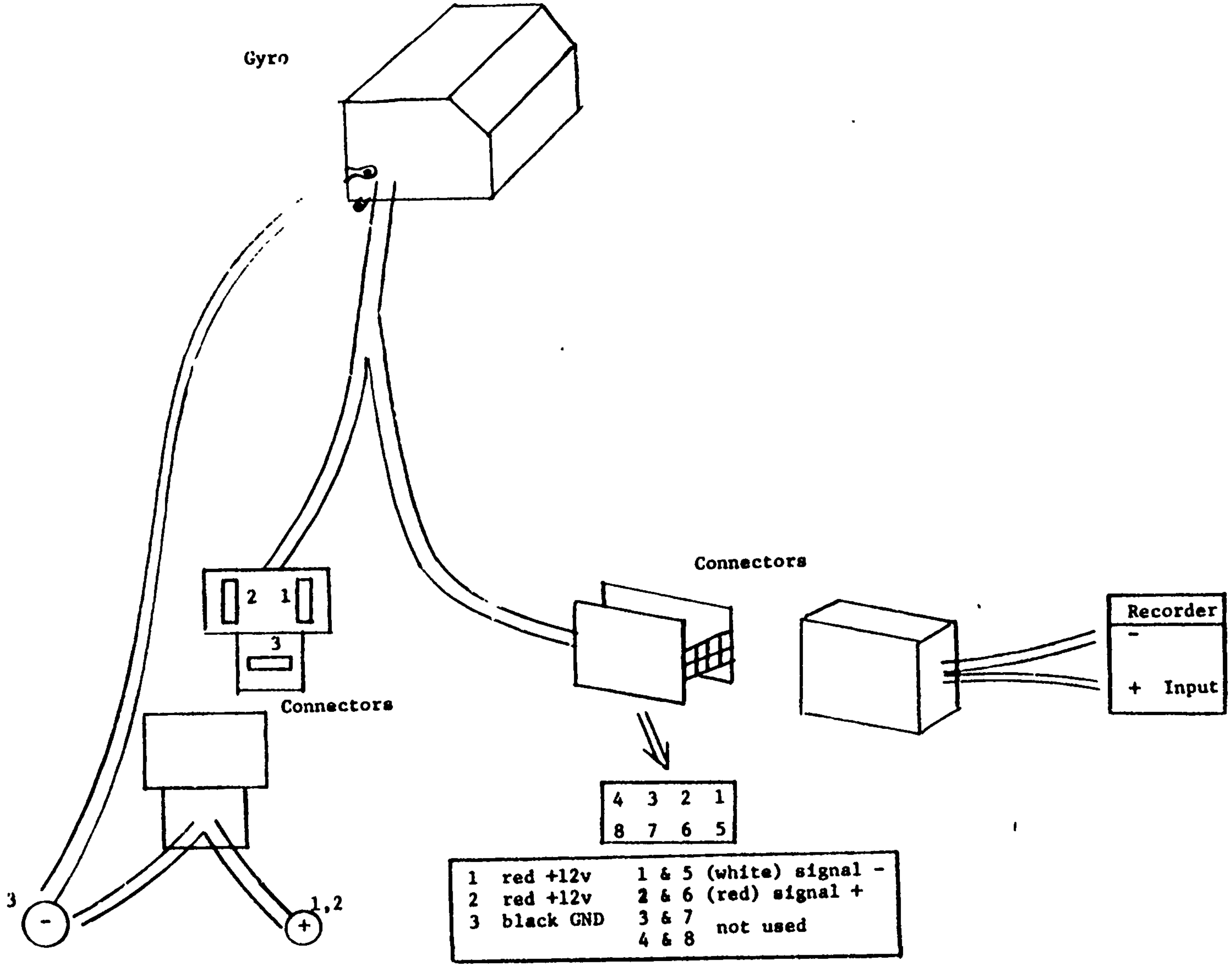


Figure 3. Schematic for gyro inputs and outputs.

As was previously mentioned, on-the-road evaluations were the second major effort. More was involved than simply installing the "Electro Gyro-Cator" in the vehicle and recording data. Knowing the form of the output from the system computer, an interface cable was built to interface the system computer with a HP9845B desk top computer. A computer program, "HONDA3", was written to interpret the system output and record the data. (See Appendix B for further information.) Once the data was in a recognizable form, it was noticed that the system computer used the outputs from the "directional" and "mileage" sensors to record its traveled path vectorly in a two dimensional coordinate system. For example, driving the vehicle from one end of the parking lot to another would result in a change in the X & Y output counts based on the initial gyro output. This indicated that the gyro startup point was arbitrary, which would be correct for a simple rate gyro. But for navigation purposes, especially with respect to Universal Transverse Mercator (UTM) coordinates, initialization with respect to north was required for each run. North initialization required knowing the initial vehicle heading (also system heading). This was accomplsihed with the aid of a Litton North Finding Module (NFM), S/N 01-100. Appendix C shows the determination of the relationship between the vehicle and the NFM, and it shows the relationship between the "Electro Gyro-Cator" coordinate system with the conventional North and East coordinate system. Calibration of the vehicle was the next step. This involved determining the distance traveled per revolution of the odometer cable. A shaft encoder was attached to the odometer cable. The encoder was wired to give one pulse per shaft rotation. The vehicle was driven on a precisely measured level course ten times. The "Electro Gyro-Cator" was also energized during these calibration runs. A distance of 1.57544[illegible] meters per cable revolution was calculated. This procedure was used in determining the actual traverse distance along the test courses. Also, during these calibration runs the system was calibrated. A scale factor of 0.048772 meters per system output count was determined. Towards the end of the evaluations, scale factors of 1.5922388 meters per odometer cable revolutions and 0.048395 meters per output count were recalculated due to the addition of air in the tires of the vehicle.

Having determined the relationship between the system and the real world, on-the-road evaluations began. This procedure consisted of starting at a known survey point, traveling in either the clockwise (CW) or the counterclockwise (CCW) direction to known survey points located in Huntsville and returning to the starting points. Two courses were used, a 24 kilometer course with little elevation change and a 57 kilometer course with a drastic elevation change. (See Appendix D for course traversion information.) No less than five trips in each direction on each course were made.

Appendix E shows northing and easting errors for each run.

IV. DISCUSSION OF RESULTS

Appendix F shows data reduction procedures and graphical representations of the various evaluations performed.

The static test results indicate a trend of 5.125 deg/hr/hr. The frequency response results indicate the gyro bandwidth is from .03 Hz to 1.0 Hz, which is adequate for the low turn rates used in land navigation. The input-output characteristics were determined as follows:

Scale factor = 0.0493 volts/deg/sec = 0.0000137 V/deg/hr

Bias = 0.7262 deg/sec = 2614.32 deg/hr

Hysteresis - none

The effects of temperature altered only the bias. At -30°C the bias was 3790.08 deg/hr and at +60°C the bias was 2760.89 deg/hr. The bias is determined during the zero-velocity updates and eliminated in the system computer.

The on-the-road evaluations were of great interest. The data reduction involved determining the northings and eastings of the system and comparing them to the true northings and eastings for the various survey points. The results are presented in two popular forms, percent of radial error per distance traveled and circular error probable (CEP).

The radial error was calculated for each point on each run. Then the root mean square (RMS) was calculated for the various trips to each survey point. The percent error was determined by dividing the RMS radial error by the actual distance traveled. A best number was determined by calculating the RMS of the percent errors. The best number is 3.519% of distance traveled. The CEP was determined for each survey point using the RMS of the northings and eastings to each point. A best number CEP was calculated from the RMS of all northing and easting errors. The best CEP is 736m. This means that for any move up to 57 Km the system will navigate to within 736 m of the destination 50 percent of the time.

V. CONCLUSIONS

This evaluation indicates the Honda "Electro Gyro-Cator" is a low accuracy system. Land navigation results of 3.5 percent of distance traveled RMS error or 736 meters CEP indicate its low accuracy. The gyroscope warmup time, 30 minutes, and roll angle susceptibility are undesirable. The odometer input and zero-velocity updates are excellent common use approaches. The system is not militarized but has excellent commercial applications, for which it was designed.

An area of the system that this evaluation does not address is the overlay screen. This device permits the operator to see the path traversed, but it has no bearing on system accuracy.

The designers did an excellent job of designing and building a commercial grade land navigator. However, the system is not acceptable for miliary use in its present configuration.

Appendix A

LABORATORY EVALUATION RAW DATA

The static drift data is shown in Table A-1. Frequency response and phase shift data is shown in Tables A-2 and A-3. Input-output characteristic data is shown in Tables A-4 through A-7.

TABLE A-1. STATIC DRIFT

Elapsed Time (hr)	Voltage (mv)	Rate (deg/hr)
0	-56.70	4140
0.5	-56.70	4140
1.0	-56.70	4140
1.5	-56.50	4126
2.0	-56.60	4133
2.5	-56.75	4144
3.0	-56.75	4144
3.5	-56.75	4144
4.0	-56.90	4154
4.5	-57.00	4162
5.0		
5.5	-57.10	4170
6.0	-57.13	4172
6.5	-57.14	4173
7.0	-57.25	4180
7.5	-57.23	4179
8.0	-57.26	4181

TABLE A-2. FREQUENCY RESPONSE DATA OF THE OSCILLATING TABLE TAKEN 14 APR 82 WITH AN AMP SETTING OF 005.

FREQUENCY (Hz)	VOLTAGE RATIO (E_o E_i)	ATTENUATION (20 log Ratio) (db)	PHASE Lag (deg)	FREQUENCY (Hz)	VOLTAGE Ratio (E_o E_i)	ATTENUATION (20 log Ratio) (db)	PHASE Lag (deg)
.03	.010	-40.00	116.4	1.60	.149	-16.54	-10.0
.05	.029	-30.75	104.0	1.65	.145	-16.77	-10.0
.10	.059	-24.58	84.6	1.75	.148	-16.59	-11.4
.15	.087	-21.21	69.4	1.85	.145	-16.77	-12.1
.20	.107	-19.41	58.2	2.00	.141	-17.02	-14.5
.25	.121	-18.34	49.6	2.25	.139	-17.14	-17.5
.30	.133	-17.52	42.0	2.50	.134	-17.46	-20.0
.35	.143	-16.89	36.3	2.75	.131	-17.65	-20.2
.40	.147	-16.65	31.0	3.00	.126	-17.99	-22.5
.45	.151	-16.42	28.0	3.25	.123	-18.20	-24.4
.50	.153	-16.31	[illegible]	3.50	.119	-18.49	-25.5
.55	.157	-16.08	20.0	4.00	.113	-18.94	-28.0
.60	.157	-16.08	19.5	4.50	.110	-19.17	-30.0
.65	.157	-16.08	16.9	5.00	.103	-19.74	-30.0
.70	.158	-16.03	13.8	5.50	.100	-20.00	-30.0
.75	.156	-16.14	10.5	6.00	.096	-20.35	-33.2
.80	.157	-16.08	10.0	6.50	.095	-20.45	-34.4
.85	.157	-16.08	9.0	7.00	.091	-20.82	-35.8
.90	.157	-16.08	7.1	7.50	.088	-21.11	-36.5
.95	.158	-16.03	5.0	8.00	.085	-21.41	-37.0
1.00	.157	-16.08	2.9	8.50	.083	-21.62	-38.1
1.05	.162	-15.81	0.3	9.00	.083	-21.62	-37.9
1.10	.159	-15.97	0.0	9.50	.082	-21.72	-38.0
1.15	.159	-15.97	-1.5	10.00	.081	-21.83	-38.4
1.20	.158	-16.03	-2.8	11.00	.081	-21.83	-40.0
1.30	.156	-16.14	-4.8	12.00	.081	-21.83	-42.0
1.40	.154	-16.25	-7.9	13.00	.075	-22.50	-44.4
1.50	.151	-16.42	-9.1	14.00	.079	-22.05	-46.9
1.55	.152	-16.36	-10.0	15.00	.077	-22.27	-50.0

TABLE A-3. FREQUENCY RESPONSE DATA OF THE RATE SENSOR AND THE OSCILLATING TABLE TAKEN 15 APR 82 WITH AN AMP SETTING OF 005.

FREQUENCY (Hz)	VOLTAGE Ratio (E_o/E_i)	ATTENUATION (20 log Ratio) (db)	PHASE Lag (deg)	FREQUENCY (Hz)	VOLTAGE Ratio (E_o/E_i)	ATTENUATION (20 log Ratio) (db)	PHASE Lag (deg)
.03	.005	-46.02	101.0	3.25	.026	-31.70	-105.5
.05	.014	-37.08	100.0	3.50	.024	-32.40	-109.5
.10	.035	-29.12	79.5	4.00	.020	-33.98	-115.5
.15	.050	-26.02	60.0	4.50	.016	-35.92	-120.0
.20	.063	-24.01	47.5	5.00	.014	-37.08	-120.0
.25	.070	-23.10	35.8	5.50	.011	-39.17	-120.0
.30	.076	-22.38	26.7	6.00	.010	-40.00	-120.0
.35	.080	-21.94	19.3	6.50	.008	-41.94	-120.0
.40	.082	-21.72	10.9	7.00	.007	-43.10	-120.0
.45	.083	-21.62	4.9	7.50	.005	-46.02	-120.0
.50	.084	-21.51	0.0	8.00	.004	-47.96	-120.0
.55	.084	-21.51	-6.8	8.50	.003	-50.46	-120.0
.60	.083	-21.62	-10.2	9.00	.002	-53.98	-120.0
.65	.080	-21.94	-15.8	9.50	.002	-53.98	-120.0
.70	.081	-21.83	-20.0	10.00	.001	-60.00	120.0
.75	.079	-22.05	-22.9	11.00	.0041	-47.74	160.0
.80	.079	-22.05	-27.9	12.00	.0035	-49.12	154.2
.85	.077	22.27	-30.0	13.00	.0032	-49.90	144.4
.90	.075	-22.50	-30.0	14.00	.0030	-50.46	134.4
.95	.075	-22.50	-36.8	15.00	.0029	-50.75	120.0
1.00	.073	-22.73	-40.0	16.00	.0027	-51.37	118.8
1.05	.071	-22.97	-41.7	17.00	.0026	-51.70	110.0
1.10	.071	-22.97	-44.9	18.09	.0025	-52.04	104.0
1.15	.069	-23.22	-47.7	19.00	.0024	-52.40	96.4
1.20	.067	-23.48	-50.0	20.00	.0024	-52.40	90.5
1.25	.065	-23.74	-50.5				
1.30	.063	-24.01	-54.0				
1.35	.063	-24.01	-56.8				
1.40	.061	-24.29	-58.9				
1.45	.061	-24.29	-60.0				
1.50	.059	-24.58	-61.9				
1.55	.057	-24.88	-63.9				
1.60	.056	-25.04	-65.4				
1.65	.055	-25.19	-67.4				
1.70	.053	25.51	-69.8				
1.75	.052	-25.68	-70.1				
1.80	.051	-25.85	-71.6				
1.85	.050	-26.02	-72.9				
1.90	.049	-26.20	-74.9				
1.95	.047	-26.56	-76.2				
2.00	.047	-26.56	-79.7				
2.25	.042	-27.54	-84.1				
2.50	.037	-28.64	-90.9				
3.00	.030	-30.46	-101.0				

TABLE A-4. RATE TABLE RESPONSE RAW DATA.

Input Rate (deg/sec)	Time/360° (sec)	Actual Rate (deg/sec)	Voltage (v)
0.1			0.041
0.2			0.045
0.3			0/049
0.4			0.053
0.5			0.057
0.75			0.069
1.0			0.080
2.0			0.124
3.0			0.172
4.0			0.220
5.0			0.264
7.5			0.335
10.	38.073	9.456	0.502
25.	15.094	23.851	1.203
50.	7.4370	48.407	2.404
100.	3.7027	97.226	4.752
125.	2.9567	121.757	5.906
150.	2.4597	146.359	7.034
200.	1.8419	195.546	9.160
250.	1.4732	244.366	11.010
150.	2.4612	146.270	7.032
125.	2.9512	121.984	5.917
100.	3.7094	97.051	4.747
50.	7.4455	48.351	2.397
25.	15.049	23.219	1.210
10.	38.187	9.427	0.500
7.5			0.382
5.0			0.265
4.0			0.219
3.0			0.172
2.0			0.125
1.5			0.103
1.0			0.080
0.75			0.069
0.5			0.058
0.4			0.053
0.3			0.049
0.2			0.045
0.1			0.041

Data taken on Genesco Rate Table @ ambient temperatures in CW direction on 20 Apr 82 after 30 minute warm-up.

TABLE A-5. RATE TABLE RESPONSE RAW DATA.

Input Rate (deg/sec)	Time/360° (sec)	Actual Rate (deg/sec)	Voltage (v)
0.1			0.0353
0.2			0.0316
0.3			0.0278
0.4			0.0233
0.5			0.0192
0.75			0.0083
1.0			-0.0026
2.0			-0.0471
3.0			-0.0940
4.0			-0.1420
5.0			-0.1892
7.5			-0.3058
10.	38.065	9.458	-0.4255
50.	7.4390	48.394	-2.3290
100.	3.6886	97.598	-4.7140
200.	1.8396	195.695	-9.1730
250.	1.4705	244.815	-11.0925
200.	1.8437	195.260	-9.1550
100.	3.7031	97.216	-4.6950
50.	7.4411	48.380	-2.3320
10.	38.058	9.459	-0.4255
7.5			-0.3065
5.0			-0.1891
4.0			-0.1434
3.0			-0.0947
2.0			-0.0479
1.0			-0.0026
0.75			0.0080
0.5			0.0192
0.4			0.0235
0.3			0.0273
0.2			0.0316
0.1			0.0354

Data taken on Genesco Rate Table @ ambient temperature in CCW direction on 21 Apr 82 after 30 minute warm-up.

TABLE A-6. RATE TABLE RESPONSE RAW DATA

CW				CCW			
Input Rate (deg/sec)	Time/360° (sec)	Actual Rate (deg/sec)	Voltage (v)	Input Rate (deg/sec)	Time/360° (sec)	Actual Rate (deg/sec)	Voltage (v)
0.1			0.0543	0.1			0.0517
0.5			0.0710	0.5			0.0351
1.0			0.0932	1.0			0.0130
5.0			0.2801	5.0			-0.1729
10.	38.058	9.459	0.5172	10.	38.066	9.457	-0.4106
25.	14.990	24.016	1.2340	25.	15.017	23.973	-1.1240
50.	7.4041	48.622	2.4380	50.	7.4223	48.502	-2.3260
75.	4.9308	73.010	3.6250	75.	4.9380	72.904	-3.5170
100.	3.6907	97.542	4.8040	100.	3.6951	97.426	-4.7030
125.	2.9467	122.171	5.9680	125.	2.9488	122.084	-5.8773
150.	2.4560	146.580	7.0940	150.	2.4528	146.771	-7.0290
200.	1.8380	195.865	9.2410	200.	1.8378	195.886	-9.1980
250.	1.4695	244.981	11.1200	250.	1.4684	245.165	-11.1315
275.	1.3356	269.542	11.2635	275.	1.3379	269.078	-11.3615
250.	1.4698	244.931	11.1200	250.	1.4693	245.015	-11.1295
200.	1.8384	195.822	9.2370	200.	1.8384	195.822	-9.1984
150.	2.4539	146.705	7.0[illegible]63	150.	2.4570	146.520	-7.0186
125.	2.9487	122.088	5.9600	125.	2.9531	121.906	-5.8714
100.	3.6895	97.574	4.8020	100.	3.6925	97.495	-4.7000
75.	4.9288	73.040	3.6230	75.	4.9377	72.908	-3.5193
50.	7.4249	48.486	2.4310	50.	7.4257	48.472	-2.3256
25.	14.982	24.029	1.2330	25.	15.027	23.951	-1.1240
10.	37.975	9.480	0.5177	10.	38.180	9.429	-0.4099
5.0			0.2789	5.0			-0.1731
1.0			0.0933	1.0			0.0128
0.5			0.0712	0.5			0.0351
0.1			0.0543	0.1			0.0519

Data taken on Genesco Rate Table @ -30°C.
CW data taken morning of 22 Apr 83 after 30 minute warm-up.
CCW data taken in the afternoon.

TABLE A-7. RATE TABLE RESPONSE RAW DATA

CW				CCW			
Input Rate (deg/sec)	Time/360° (sec)	Actual Rate (deg/sec)	Voltage (v)	Input Rate (deg/sec)	Time/360° (sec)	Actual Rate (deg/sec)	Voltage (v)
0.1			0.0400	0.1			0.0349
0.5			0.0558	0.5			0.0190
1.0			0.0785	1.0			-0.0031
5.0			0.2628	5.0			-0.1872
10.	38.214	9.421	0.4982	10.	38.427	9.368	-0.4209
25.	15.085	23.865	1.2040	25.	15.143	23.773	-1.1270
50.	7.4500	48.322	2.3930	50.	7.4750	48.161	-2.3170
75.	4.9661	72.491	3.5620	75.	4.7800	75.314	-3.5570
100.	3.7114	96.998	4.7320	100.	3.7077	97.095	-4.6800
125.	2.9581	121.700	5.8900	125.	2.9510	121.993	-5.8580
150.	2.4617	146.240	7.0090	150.	2.4663	145.968	-6.9680
200.	1.8450	195.122	9.1240	200.	1.8431	195.323	-9.1360
250.	1.4744	244.167	10.9900	250.	1.4771	243.721	-11.0260
275.	1.3388	268.898	11.2857	275.	1.3397	268.717	-11.2335
250.	1.4760	243.902	10.9850	250.	1.4736	244.300	-11.0460
200.	1.8506	194.532	9.1035	200.	1.8475	194.858	-9.1170
150.	2.4607	146.300	7.0140	150.	2.4684	145.843	-6.9640
125.	2.9604	121.605	5.8850	125.	2.9613	121.568	-5.8380
100.	3.7098	97.040	4.7300	100.	3.7161	96.876	-4.6680
75.	4.9609	72.567	3.5640	75.	4.9667	72.483	-3.4960
50.	7.4505	48.319	2.3930	50.	7.4519	48.310	-2.3230
25.	15.027	23.957	1.2080	25.	15.078	23.876	-1.1330
10.	38.180	9.429	0.4990	10.	38.150	9.436	-0.4233
5.0			0.2622	5.0			-0.1892
1.0			0.0782	1.0			-0.0040
0.5			0.0564	0.5			0.0186
0.1			0.0403	0.1			0.0346

Data taken on Genesco Rate Table @ +60°C.
CW data taken morning of 21 Apr 82 after 30 minute warm-up.
CCW taken in the afternoon.

Appendix B

SYSTEM INTERFACE PROGRAM

"HONDA 3" simply allows the operator to make initial comments, record the output from the system computer, and make comments at each survey point. A listing of "HONDA 3" follows.

```
10    ! PROGRAM HONDA3
20    OPTION BASE 0
30    INTEGER X(12000),Y(12000),Theta(12000)
40    DIM F_name$[6],Time$[14],Date$[40],Descr$[80],Comm$[80],Route$[160]
50    DIM Start_loc$[80],Dummy$[80],Waypt$[80],Time1$[14]
60    PRINTER IS 16
70    PRINT "INSERT TAPE YOU WISH DATA TO RESIDE ON IN T14"
80    BEEP
90    INPUT "THEN ENTER FILE NAME WHERE DATA IS TO BE STORED (6 CHARACTERS MAX)"
,F_name$
100 ON ERROR GOTO Create_err
110   CREATE F_name$&":T14",420,256
120   BEEP
130   INPUT "ENTER DATE (40 CHARACTERS MAX)",Date$
140   BEEP
150   INPUT "ENTER TEST DESCRIPTION (40 CHARACTERS MAX.)",Descr$
160   BEEP
170   INPUT "ENTER COMMENTS, IF ANY (80 CHARACTERS MAX.)",Comm$
180   BEEP
190   INPUT "ENTER ROUTE DESCRIPTION (160 CHARACTERS MAX,)",Route$
200   BEEP
210   INPUT "ENTER STARTING LOCATION (80 CHARACTERS MAX.)",Start_loc$
220   BEEP
230   INPUT "NEED TO SET THE CLOCK (Y/N)?",Dummy$
240   !
250   !  SET CLOCK I/O SELECT CODE
260   !
270   Clock=10
280   IF Dummy$="Y" THEN GOSUB Set_time
290   IF Dummy$="N" THEN GOSUB Get_time
300   ASSIGN F_name$&":T14" TO #1
310   BUFFER #1
320   PRINT #1;Date$,Descr$,Comm$,Route$,Start_loc$,Time$
330   PRINTER IS 0
340   PRINT "DATE:",LIN(1),Date$
350   PRINT "TEST DESCRIPTION:",LIN(1),Descr$
360   PRINT "COMMENTS:",LIN(1),Comm$
370   PRINT "ROUTE DESCPIPTION:",LIN(1),Route$
380   PRINT "STARTING LOCATION:",LIN(1),Start_loc$
390   PRINT "START TIME:",LIN(1),Time$
400   BEEP
410   INPUT "HOW FAR DO YOU EXPECT TO TRAVEL BETWEEN CHECKPOINTS (Km)?",Delta
420   ! SET UP GRAPHICS DISPLAY TO BE CLOSE TO THE EXPECTED DISTANCE BETWEEN CHE
CKPOINTS.
430   Max=(INT(Delta/5)+1)*5
440   !
450   !  SET FLAGS:
460   !
470   !  FLAG 1: SET BY HONDA INTERRUPT.  CAN BE RESET THEN CHECKED BY OTHER
480   !          ROUTINES TO SEE IF VEHICLE IS MOVING.
490   !  FLAG 2: WHEN RESET, TELLS HONDA INTERRUPT ROUTINE TO READ THE REAL
500   !          TIME CLOCK.  USED TO RECORD THE TIME OF FIRST VEHICLE MOTION.
510   Flag1=0
520   Flag2=0
530   !  N IS THE INDEX ON THE X, Y, & Theta MATRICES
540   N=0
550   !  SET UP INTERRUPT SYSTEM.
560   !  I/O INTERRUPT CONFIGURATION:
570   !  SELECT CODE/KEY                 DEVICE/FUNCTION
580   !        2                         HONDA NAVIGATOR
590   !     KEY #1                       CHECKPOINT LOG
600   !     KEY #7                       FORCED FILE CLOSING
610   !        6                         REAL TIME CLOCK
620   Honda=2
630   ON INT #Honda,2 GOSUB Int_honda
640   READ IO Honda,5;Reg5
```

```
650   Reg5=BINIOR(Reg5,1)
660   WRITE IO Honda,5;Reg5
670   Reg5=BINAND(Reg5,-2)
680   WRITE IO Honda,5;Reg5
690   CONTROL MASK Honda;128
700   CARD ENABLE Honda
710   ON KEY #1,1 GOSUB Update
720   ON KEY #7,3 GOSUB Close
730   PRINTER IS 0
740   Flag3=1
750   BEEP
760   PRINT LIN(2),"READY TO ROLL!!",LIN(2
770   BEEP
780 L1:  IF Flag1=0 THEN GOTO L1
790   GOSUB List
800   Flag1=0
810   GOTO L1
820 Int_honda:  !
830   ! HONDA INTERRUPTS SERVICED HERE...
840   READ IO Honda,5;Reg5
850   Reg5=BINIOR(Reg5,1)
860   WRITE IO Honda,5;Reg5
870   Reg5=BINAND(Reg5,-2)
880   WRITE IO Honda,5;Reg5
890   WRITE IO Honda,4;-1
900   READ IO Honda,4;X(N)
910   WRITE IO Honda,4;-2
920   READ IO Honda,4;Y(N)
930   WRITE IO Honda,4;-3
940   READ IO Honda,4;Theta(N)
950   N=N+1
960   Flag1=1
970   IF Flag2<>0 THEN GOTO Ret
980   Flag2=1
990   GOSUB Get_time
1000  Time1$=Time$
1010 Ret: CARD ENABLE Honda
1020  RETURN
1030 Plot: !
1040  PRINTER IS Graphics
1050  IF N<>1 THEN GOTO C1
1060  X1=X(0)
1070  Y1=Y(0)
1080  X2=X1
1090  Y2=Y1
1100 C1: ! N2=N-1
1110  X1=X2
1120  Y1=Y2
1130  X2=X(N2)
1140  Y2=Y(N2)
1150 C2: !
1160  Dx1=X1+K1
1170  Dy1=Y1+K1
1180  Dx2=X2+K1
1190  Dy2=Y2+K1
1200  Dx=Dx2-Dx1
1210  Dy=Dy2-Dy1
1220  IF Dx<-K2 THEN GOTO C3
1230  IF Dy>K2 THEN GOTO C4
1240  GOTO C5
1250 C3:  Dx=Dx+K3
1260  GOTO C5
1270 C4:  Dx=Dx-K3
1280 C5: Xp=Xp+Dx
1290  IF Dy<-K2 THEN GOTO C6
1300  IF Dy>K2 THEN GOTO C7
```

```
1310  GOTO C8
1320 C6: Dy=Dy+K3
1330  GOTO C8
1340 C7: Dy=Dy-K3
1350 C8: Yp=Yp+Dy
1360  DRAW Xp,Yp
1370  RETURN
1380 Update: '
1390  Flag3=1
1400  GOSUB List
1410  Flag1=0
1420  PRINTER IS 16
1430  BEEP
1440  PRINT "VEHICLE MUST BE STOPPED TO PERFORM UPDATE."
1450  FOR Dummy=1 TO 7000
1460  NEXT Dummy
1470  IF Flag1=0 THEN GOTO Ok
1480  BEEP
1490  PRINT "THIS VEHICLE IS STILL MOVING"
1500  GOTO Update
1510 Ok: '
1520  BEEP
1530  PRINT "PLEASE DO NOT MOVE THIS VEHICLE UNTIL"
1540  PRINT "I TELL YOU TO."
1550  PRINTER IS 0
1560  GOSUB Get_time
1570  PRINT LIN(2),"UPDATE"
1580  PRINT "CURRENT TIME---",Time$
1590  BEEP
1600  INPUT "ENTER WAYPOINT DATA (80 CHARACTERS MAX.)",Waypt$
1610  REDIM X(N-1),Y(N-1),Theta(N-1)
1620  PRINT #1;Time1$,Waypt$,Time$,N,X(*),Y(*),Theta(*)
1630  REDIM X(12000),Y(12000),Theta(12000)
1640  N=0
1650  Flag2=0
1660  PRINT "WAYPOINT DESCRIPTION:"
1670  PRINT Waypt$
1680  PRINT "VEHICLE MOTION FLAG =",Flag1
1690  PRINTER IS 16
1700  BEEP
1710  INPUT "ARE WE HOME? (Y/N)",Dummy$
1720  IF Dummy$="Y" THEN GOTO Home
1730  Flag3=1
1740  PRINTER IS 0
1750  BEEP
1760  PRINT "READY TO ROLL!",LIN(2)
1770  RETURN
1780 Home: '
1790  BEEP
1800  INPUT "ENTER FINAL COMMENTS ABOUT THE TEST, IF ANY (80 CHARACTERS MAX)",Du
mmy$
1810  PRINT #1;Dummy$,END
1820  ASSIGN * TO #1
1830  STOP
1840  END
1850 Set_time: '
1860  Time$=RPT$(":",14)
1870  BEEP
1880  OUTPUT 16;"ENTER EACH TIME GROUP. USE A TWO-DIGIT NUMBER AND PRESS CONT.
"

1890  LINPUT "WHAT MONTH? (01-12)",Time$[1,2]
1900  Month=VAL(Time$[1,2])
1910  BEEP
1920  ON Month GOTO One,Feb,One,Zero,One,Zero,One,One,Ze   One,Zero,One
1930 One: LINPUT "WHAT DAY?(01 to 31)",Time$[4,5]
1940  GOTO Hour
```

```
1950 Zero:  LINPUT "WHAT DAY?(01 to 30)",Time$[4,5]
1960  GOTO Hour
1970 Feb: LINPUT "WHAT DAY?(01 to 29)",Time$[4,5]
1980  BEEP
1990 Hour: LINPUT "WHAT HOUR?(00 - 23)",Time$[7,8]
2000  BEEP
2010  LINPUT "WHAT MINUTE?(00 - 59)",Time$[10,11]
2020  BEEP
2030  LINPUT "WHAT SECOND?(00 - 59)",Time$[13,14]
2040  OUTPUT Clock;"A"
2050  OUTPUT Clock;"S";Time$
2060  BEEP
2070  OUTPUT 16;"TIME SETTING INITIATED AT ",Time$
2080  OUTPUT 16;"DO NOT RESET OR REMOVE POWER FOR 2 MINUTES!!"
2090  RETURN
2100 Get_time: !
2110  OUTPUT Clock;"R"
2120  ENTER Clock;Time$
2130  RETURN
2140 Label: !
2150  D_label=1
2160  IF Max>5 THEN D_label=5
2170  !  SET CHARACTER SIZE
2180  CSIZE 2.5
2190  !  CENTER CHARACTERS UNDER TICK MARKS
2200  LORG 6
2210  FOR I=-Max TO Max STEP D_label
2220  MOVE I,0
2230  LABEL USING "/DDD";I
2240  NEXT I
2250  !  CENTER CHARACTERS TO LEFT OF Y AXIS TICKS
2260  LORG 8
2270  !  LOOP TO LABEL Y AXIS
2280  FOR I=-Max TO Max STEP D_label
2290  MOVE 0,I
2300  LABEL USING "DDDX";I
2310  NEXT I
2320  !  DRAW CIRCLES WITH TIC RADII
2330  MOVE 0,0
2340  DEG
2350  FOR K=0 TO 90
2360  FOR J=Major TO Max+2*Major STEP Major
2370  PDIR K*4
2380  MOVE 0,0
2390  IPLOT J,0
2400  NEXT J
2410  NEXT K
2420  RETURN
2430 List: !
2440  PRINTER IS 16
2450  PRINT X(N-1),Y(N-1),Theta(N-1)
2460  PRINTER IS 0
2470  IF Flag3=0 THEN GOTO Test
2471  PRINT X(N-1),Y(N-1),Theta(N-1)
2472  PRINT ""
2480  Flag3=0
2490  RETURN
2500 Test: !
2510  IF ABS(X(N-1)-X(N-2))>32767 THEN GOTO Print
2520  IF ABS(Y(N-1)-Y(N-2))>32767 THEN GOTO Print
2521  RETURN
2522 Print: !
2530  PRINT X(N-2),Y(N-2),Theta(N-2)
2540  PRINT X(N-1),Y(N-1),Theta(N-1)
2550  PRINT " "
2560  RETURN
```

```
2570 Create_err:  ! IF THE OPERATOR INPUTS A FILENAME THAT ALREADY
2580  ! EXISTS, CONTROL TRANSFERS HERE.
2590  OFF ERROR
2600  IF ERRN<>54 THEN GOTO Bad_err
2610  PRINT F_name$;" ALREADY EXISTS; SHOULD I OVERWRITE IT (Y/N)?"
2620  INPUT Dummy$
2630  IF Dummy$="Y" THEN GOTO 120
2640  GOTO 90
2650 Close:  ! FORCED FILE CLOSING.
2660  ASSIGN * TO #1
2670  STOP
2680  END
2690 Bad_err: BEEP
2700  PRINT "FATAL ERROR; ERROR NUMBER ";ERRN
2710  GOTO Close
2720  STOP
2730  END
```

Appendix C

VEHICLE HEADING DETERMINATION AND COORDINATE SYSTEMS RELATIONSHIP

Knowing the vehicle's initial heading was crucial, since the "Electro Gyro-Cator" only kept up with the change in heading. The method used to determine initial heading needed to be quick and simple, since many runs were to be taken. It was decided to use a Litton North Finding Module (NFM) to meet this requirement. The NFM was mounted to the vehicle cabinet. Next the misalignment between the vehicle heading (vehicle centerline/system heading) and the NFM had to be determined. (Refer to Figure C-1 for determination.) First, a theodolite, T1, was mounted on the pedestal in the Clean Room of Building 5400. T1 was aimed directly at the Redstone Arsenal Astro Survey Point Monument (RSA). The angle between T1's line of sight (LOS) and north is known to be 88° 48' 48". Another theodolite, T2, was mounted on RSA and collimated with T1. T2 was set to read 268° 48' 48", the back angle of 88° 48' 48". This reading was labeled R1. The vehicle was then placed close to RSA. The midpoint of each axle was determined, and a string pulled across the midpoints. Two more theodolites, T3 and T4, were placed directly over the string and collimated. The T3/T4 LOS was then the same as the string which was the vehicle heading. T2 and T3 were then collimated. T2's reading, R2, was 227° 40' 24". T3 was set at the back angle, 47° 40' 24". T3 and T4 were again collimated, and the T3 reading, R4, was 359° 46' 39". This was the vehicle heading. Next the NFM was energized. The NFM reading was 359° 48' 31.5". Therefore, the misalignment between the vehicle heading and the NFM was 000° 01' 52.5" $\pm$ 000° 00' 50" (the accuracy of the NFM) counterclockwise.

The relationship between the system coordinate system and the real world (north and east) had to be established. The system outputs were X, Y, and θ, which correlated to the X and Y position and vehicle heading at that instant. Figure C-2 represents the output graphically and also shows the limits on the rollover type of data acquisition used by the system. Refer to Figure C-3 for the following coordinate system determination explanation. The vehicle is going to travel from point 0 to point P. The vehicle path is represented by the vector $\overline{R}$. The initial heading of the vehicle is due north. The "Electro Gyro-Cator" system comes up with an arbitrary initial heading, θ. Knowing θ and refering to Figure C-2, the X Y coordinate system is known to be rotated $\theta°$. Therefore, from Figure C-3(a)

$$\overline{R} = \overline{X} + \overline{Y} \qquad \text{(C-1)}$$

and

$$\overline{X} = X\hat{x} \qquad \text{(C-2)}$$

$$\overline{Y} = Y\hat{y} \qquad \text{(C-3)}$$

where $\hat{x}$ and $\hat{y}$ are unit vectors.

From C-3(b)

$$\overline{X} = X \cos \theta\hat{N} + X \sin \theta\hat{E} \qquad \text{(C-4)}$$

and

$$\overline{Y} = -(-Y) \sin \theta\hat{N} + (-Y) \cos \theta\hat{E} \qquad \text{(C-5)}$$

where $\hat{N}$ and $\hat{E}$ are unit vectors.

The resultant northings and eastings of $\overline{R}$ are simply the sum of Eqs (C-4) and (C-5). Solving afor N and E gives the following

$$N = X \cos \theta + Y \sin \theta \qquad \text{(C-6)}$$

$$E = X \sin \theta - Y \cos \theta \qquad \text{(C-7)}$$

Therefore, knowing the distance in the X and Y directions and knowing the angle between the system's coordinate system and the vehicle heading, the change in northing and easting can be easily computed using Eqs (C-6) and (C-7).

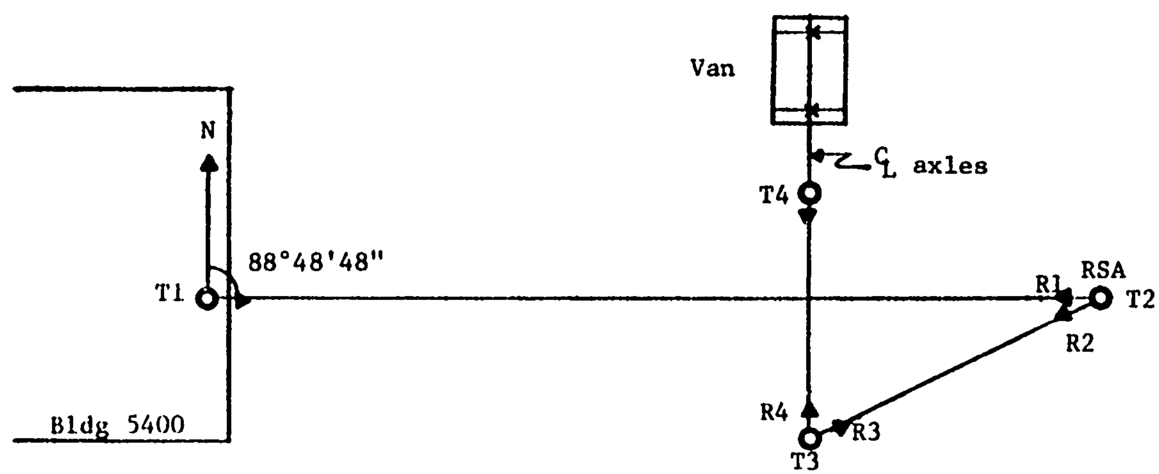
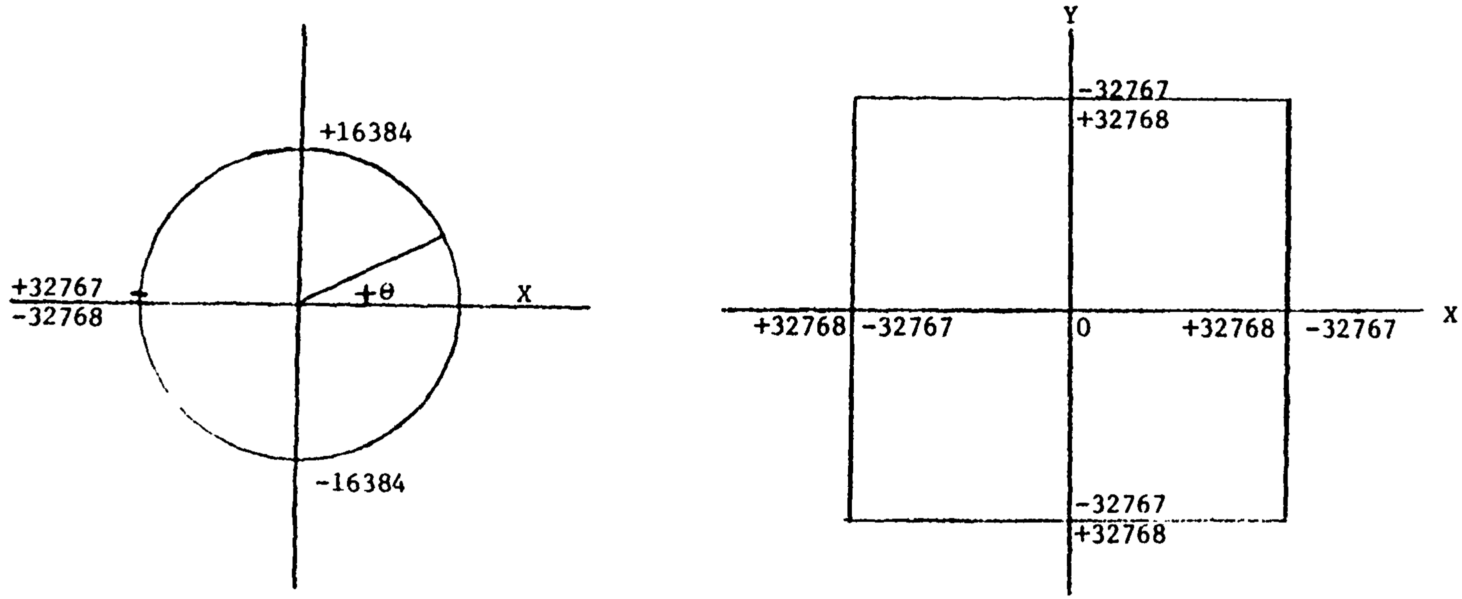


Figure C-1. Vehicle heading determination.



Gyro Coordinate System

Vector Coordinate System

Figure C-2. "Electro Gyro-Cater" coordinate systems.

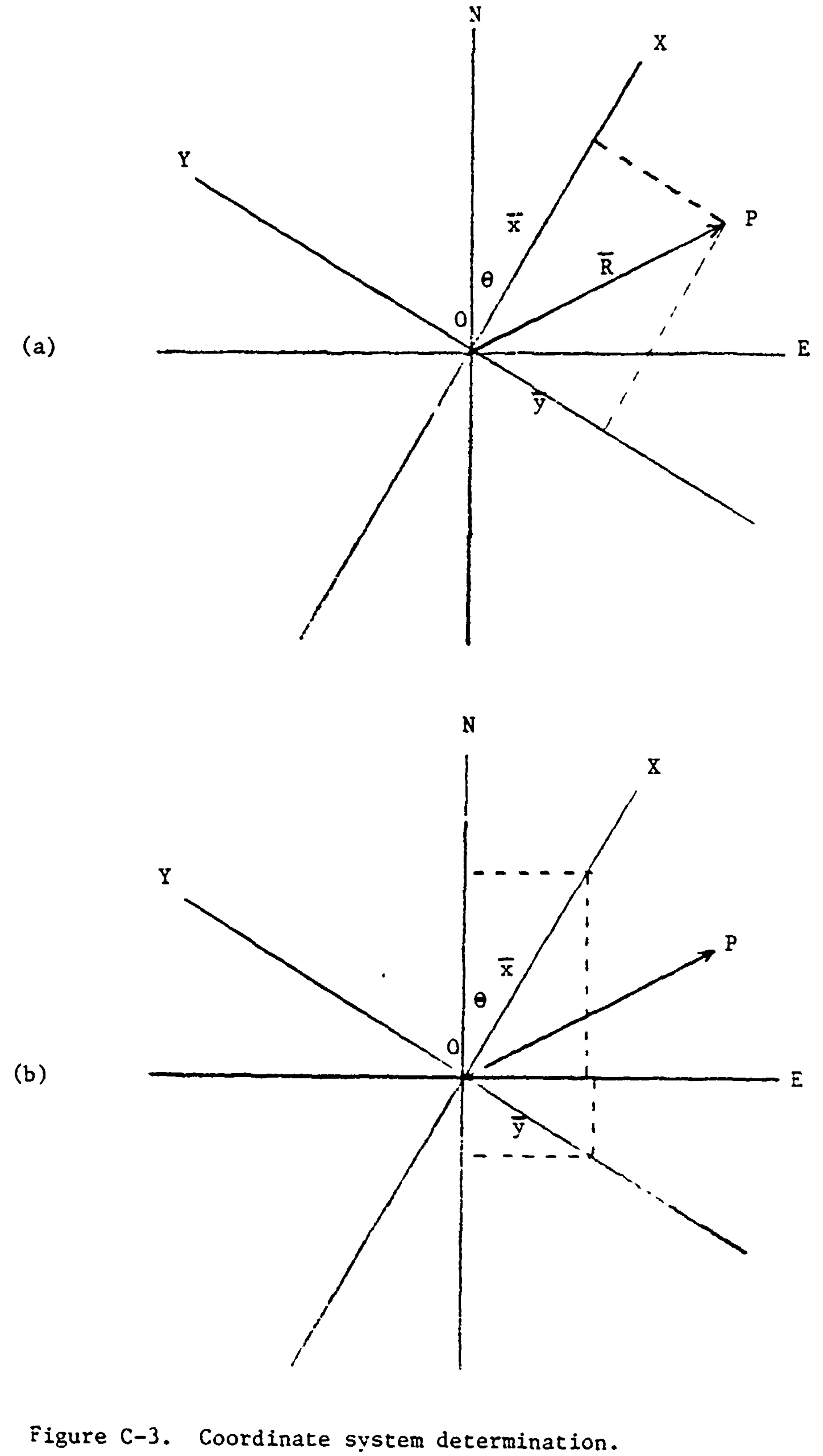


Figure C-3. Coordinate system determination.

Appendix D

COURSE TRAVERSION

The vehicle was driven on two courses for the road evaluations. No less than five each runs were made in the CW and CCW directions on each course. Figure D-1 shows a map of the short, level 24 Km course. Figure D-2 shows the long 57 Km course, which includes an elevation change of approximately 300 feet. Tables D-1 and D-2 show the distances between survey points. As can be seen, the distance changes depending on direction (CW or CCW).

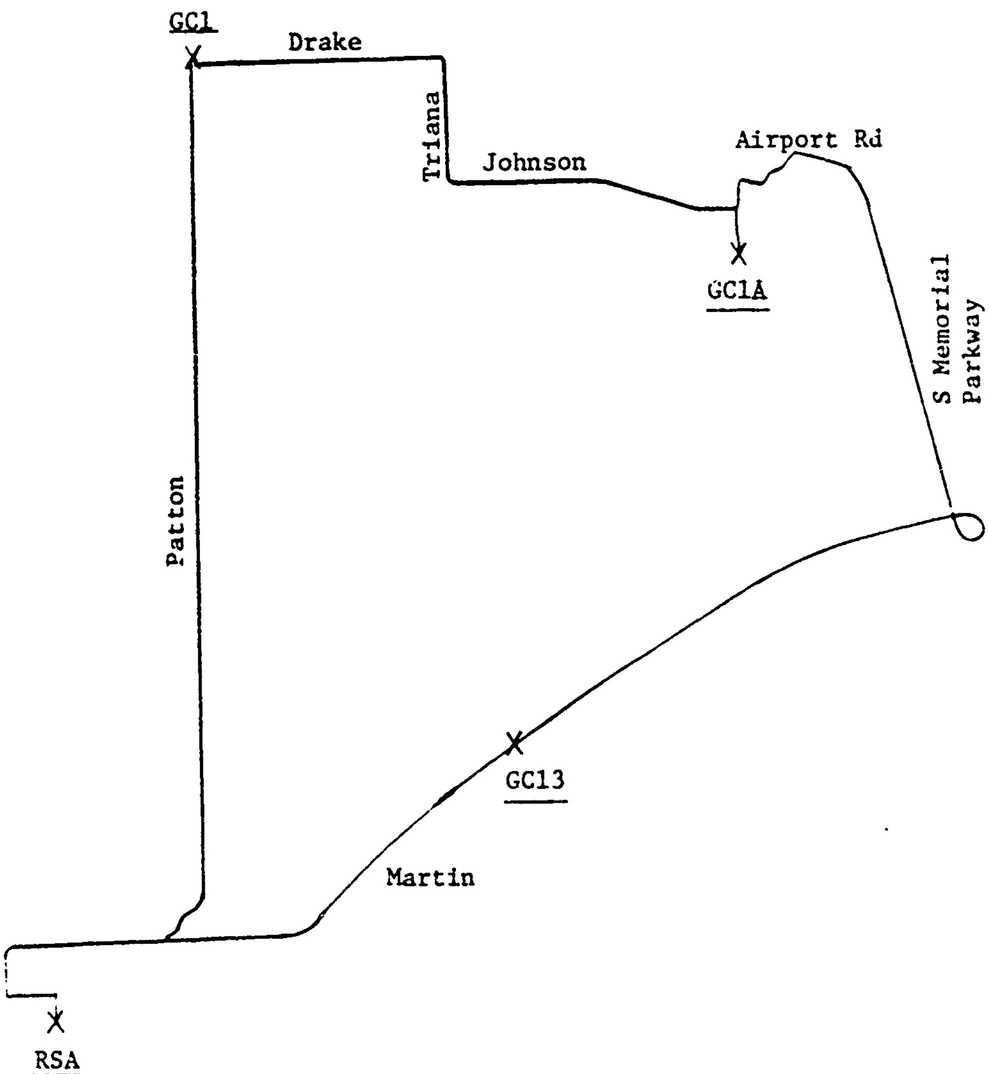


Figure D-1. 24 Km course.

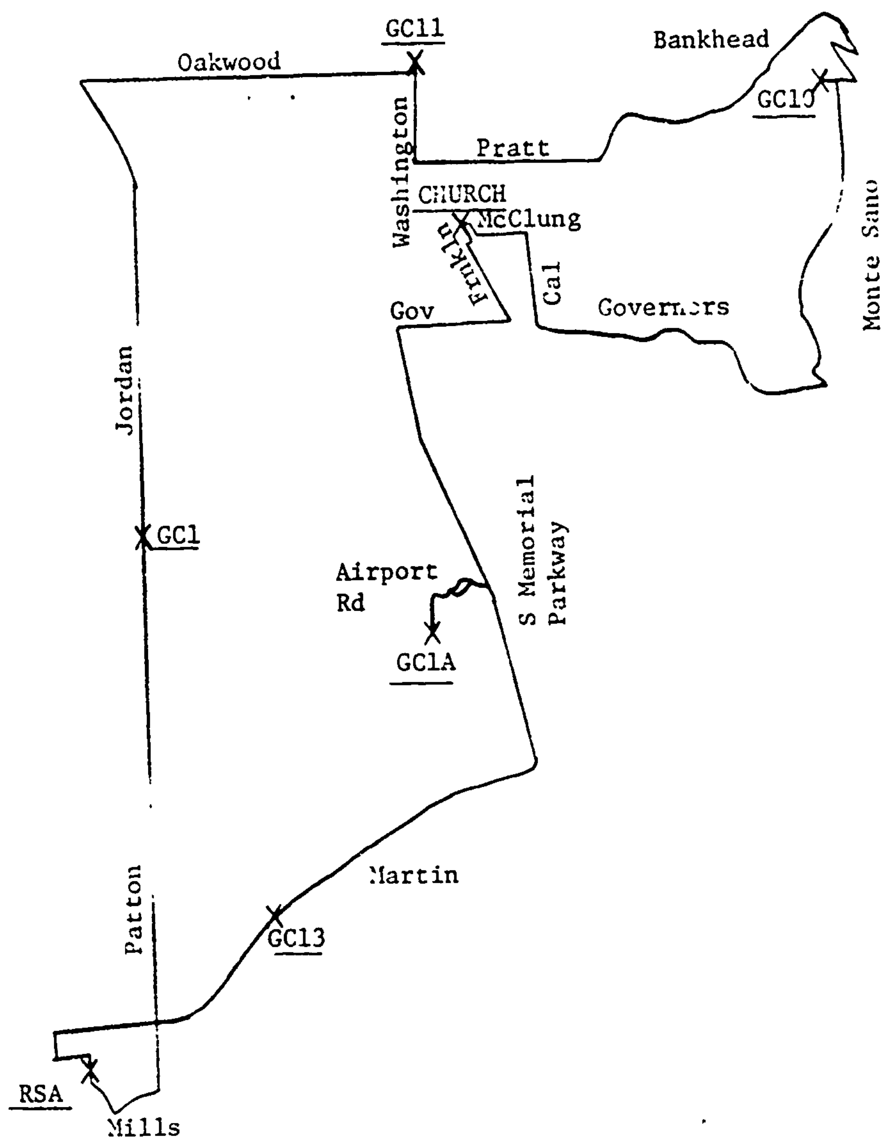


Figure D-2. 57 Km course.

TABLE D-1. 24 KM COURSE DISTANCES

Direction	From	To	Distance (m)
CW	RSA	GC1	8413
	GC1	GC1A	4703
	GC1A	GC13	6968
	GC13	RSA	4680
CCW	RSA	GC13	4441
	GC13	GC1A	7638
	GC1A	GC1	4713
	GC1	RSA	7560

TABLE D-2. 57 KM COURSE DISTANCES

Direction	From	To	Distance (m)
CW	RSA	GC1	8017
	GC1	GC11	10100
	GC11	GC10	9288
	GC10	Church	10469
	Church	GC1A	7534
	GC1A	GC13	6968
	GC13	RSA	4680
CCW	RSA	GC13	4441
	GC13	GC1A	7638
	GC1A	Church	7688
	Church	GC10	10540
	GC10	GC11	9180
	GC11	GC1	10163
	GC1	RSA	7909

APPENDIX E

NORTHING AND EASTING ERRORS

TABLE E-1. 24 KM COURSE

Direction	From	To	Run	ERROR Northing (m)	ERROR Easting (m)
CW	RSA	GC1	2.1	70	639
			4.1	117	349
			6.1	123	201
			8.1	106	249
			10.1	194	-224
			12.1	-5	813
	GC1	GC1A	2.2	-416	468
			4.2	-33	345
			6.2	-15	187
			8.2	6	285
			10.2	39	-230
			12.2	-530	620
	GC1A	GC13	2.3	32	-253
			4.3	-45	175
			6.3	111	-115
			8.3	126	-7
				-328	78
	GC13	RSA	2	729	-618
			4	30	58
			6	384	-323
			8	344	-201
			12	54	-170

TABLE E-2. 24 KM COURSE

Direction	From	To	Run	ERROR Northing (m)	ERROR Easting (m)
CCW	RSA	GC13	1.1	28	84
			3.1	56	48
			5.1	-78	135
			7.1	26	90
			9.1	-86	129
			11.1	95	39
	GC13	GC1A	1.2	155	87
			3.2	252	60
			5.2	062	355
			7.2	173	139
			9.2	-47	397
			11.2	207	-41
	GC1A	GC1	1.3	194	11
			3.3	251	-22
			5.3	-10-	300
			7.3	31	4
			9.3	164	416
			11.3	-259	-262
	GC1	RSA	3	146	-63
			5	-87	148
			7	-128	409
			9	134	42
			11	-454	853

TABLE E-3. 57 KM COURSE

Direction	From	To	Run	ERROR Northing (m)	ERROR Easting (m)
CCW	RSA	GC13	1.1	-62	125
			2.1	-161	174
			3.1	-47	97
			4.1	-233	203
			5.1	-262	207
	GC13	GC1A	1.2	28	332
			2.2	-178	452
			3.2	38	167
			4.2	-323	608
			5.2	-303	718
	GC1A	Church	1.3	73	703
			2.3	-148	783
			3.3	132	125
			4.3	-623	988
			5.3	-434	1676
	Church	GC10	1.4	-487	1004
			2.4	-639	1080
			3.4	170	-5
			4.4	-816	936
			5.4	-1517	2178
	GC10	GC11	1.5	-389	899
			2.5	194	1113
			3.5	-826	-173
			4.5	-1482	760
			5.5	-614	2222
	GC11	GC1	1.6	-477	1004
			2.6	903	45
			3.6	-1595	1459
			4.6	-2112	1957
			5.6	-58	1411
	GC1	RSA	1	-619	1312
			2	1014	-1254
			3	-1731	3271
			4	-2302	3173
			5	42	448

TABLE E-4. 57 KM COURSE

Direction	From	To	Run	ERROR Northing (m)	ERROR Easting (m)
CCW	RSA	GC1	6.1	-22	449
			7.1	-10	115
			8.1	-20	338
			9.1	17	-30
			10.1	-10	255
	GC1	GC11	6.2	-340	945
			7.2	233	23
			8.2	-445	794
			9.2	81	-144
			10.2	-176	528
	GC11	GC10	6.3	-765	945
			7.3	911	69
			8.3	-1007	760
			9.3	260	-82
			10.3	-444	552
	GC10	Church	6.4	-97	767
			7.4	249	215
			8.4	4	458
			9.4	246	-154
			10.3	9	427
	Church	GC1A	6.5	42	66
			7.5	248	1148
			8.5	202	-487
			9.5	276	-108
			10.5	124	-104
	GC1A	GC13	6.6	331	-414
			7.6	97	1617
			8.6	456	-969
			9.6	313	-218
			10.6	400	-515
	GC13	RSA	6	752	-608
			7	-306	1893
			8	769	-1121
			9	289	-200
			10	732	-671

APPENDIX F

DATA REDUCTION

The trend of the drift of the gyro with no input rate was calculated by determining the difference of the beginning and ending output rates and dividing by the total time. Figure F-1 shows static drift results.

Determining the frequency response is straight forward. The Frequency Response Analyzer gave voltage ratio outputs. The attenuation in decibels is calculated by

$$db = 20 \log (\text{Ratio}) \qquad (F\text{-}1)$$

Making this calculation for all points on both the Oscillating Table and the Table plus the gyro allows for easy gyro response determination. The gyro frequency response is the difference between the curves. (See Figure F-2.) Figure F-3 shows the phase shift. For good frequency response the flat portion of the curve is the best place to operate. Figure F-4 shows that the best operable range is up to 1.0 Hz.

The input-output characteristics were determined at various temperatures. Figures F-5 through F-10 show plots of rate table inputs versus gyro outputs. The scale factor (SF) is simply the slope of the curve. The bias is simply the y-intercept of the curve. Table F-1 shows the SF and bias for each temperature. Hysteresis is determined by how well the device follows the accelerated path when it is decelerated. It can also be seen from Figures F-5 through F-10 that the accelerated and decelerated paths were the same.

The radial error for each point was calculated thusly:

$$RE = \sqrt{E_N^2 + E_E^2} \qquad (F\text{-}2)$$

where E_N and E_E are northing and easting errors, respectively. Tables F-2 through F-5 show the individual radial errors and the percent error of distance traveled, using Appendix D. Statistical calculations; root mean square (RMS), mean ($\bar{X}$), standard deviation (1σ); of the errors were made for pertinent runs, e.g. all runs in the CCW direction on the 24 Km course from RSA to GC13. The results of these calculations are presented in Tables F-6 through F-9. The percent of the RMS radial error per distance traveled was then determined. The results are shown in Table F-10. Figure F-11 shows a plot of distance traveled versus RMS radial error. A best number percentage was determined by calculating the RMS of all the percent errors. This calculation turned out to be 3.519% with a $\bar{X}$ of 3.220% and 1σ of 1.420%.

The circular error probable (CEP) was also determined for each survey point. CEP is calculated thusly:

$$CEP = .589\ (N_{RMS} + E_{RMS}) \qquad (F\text{-}3)$$

where N_{RMS} and E_{RMS} are the RMS northing and easting errors respectively. This approximation means 50 percent of the data points will be within a circle with a radius of the CEP distance. Table F-11 shows the CEP's. Figure F-12 shows a plot of the distances traveled versus CEP. A best number CEP of 736 m was calculated using the RMS of all northing and easting errors. The RMS of all northing errors was 501 m, and the RMS of all easting errors was 748 m.

A computer program "REDUCE" was written to aid in the data reduction process. The capabilities of "REDUCE" are to print sections of the raw data, compute distances traveled, plot the path taken, and print the journey log. A listing of program "REDUCE" and sample outputs are as follows:

```
10    ! ---- PROGRAM 'REDUCE' ---- !
20    ! THIS PROGRAM PROVIDES ROUTINES TO REDUCE THE HONDA LAND NAVIGATOR DATA.
30    !
40    !
50    OPTION BASE 1
60    REAL X(1200),Y(1200)
70    INTEGER A(1200),B(1200),Theta(1200)
80    DIM F_name$[6],Time$[14],Strings$(7)[160]
90    DIM Dummy$[80],Half1$[30],Half2$[30],Half3$[20]
100   MAT A=ZER
110   MAT B=ZER
120   MAT Theta=ZER
130   Nnn=1
150   D$=CHR$(132)
160   A$=CHR$(128)
170   PRINTER IS 16
180   PRINT PAGE
190   INPUT "INSERT DATA TAPE INTO T14 AND ENTER FILE NAME.",F_name$
200   ASSIGN F_name$&":T14" TO #1
210   BUFFER #1
220   ON ERROR GOTO Bad_file
230   ON END #1 GOTO End_file
240   GOSUB Read_heading
250   OFF END #1
260   OFF ERROR
261   INPUT "Enter scale factor. Short runs and LT1-LT5 SF=0.048772. LT6-LT10 SF
=0.048395.",Scale
270   Way_no=1
280   PRINTER IS 0
290   PRINT LIN(3),D$&"File name:"&A$;LIN(1),TAB(3),F_name$
300   PRINT D$&"TEST DATE:"&A$,LIN(1),TAB(3),Strings$(1)
310   PRINT D$&"Test description:"&A$,LIN(1),TAB(3),Strings$(2)
320   PRINT D$&"Comments:"&A$,LIN(1),TAB(3),Strings$(3)
330   PRINT D$&"Route description:"&A$,LIN(1),TAB(3),Strings$(4)
340   PRINT D$&"Starting location:"&A$,LIN(1),TAB(3),Strings$(5)
350   PRINT D$&"Test start time:"&A$,LIN(1),TAB(3),Strings$(6),LIN(3)
360 Avail_routines:        ! LISTING OF ROUTINES THIS PROGRAM SUPPORTS.
370   PRINTER IS 16
380   PRINT PAGE
390   PRINT "Available routines:"
400   PRINT LIN(1),TAB(10),"1) Search for particular data items."
410   PRINT TAB(10),"2) Print sections of data."
420   PRINT TAB(10),"3) Compute distances travelled."
430   PRINT TAB(10),"4) Plot course on graphics screen."
440   PRINT TAB(10),"5) Print journey log (comments, times, waypoints,etc.)."
450   PRINT TAB(10),"6) End program."
460   INPUT "Enter number of desired routine:",Routine
470   ! CHECK TO SEE IF VALID ROUTINE.
480   IF (Routine<1) OR (Routine>6) THEN GOTO Bad_routine
490   ON Routine GOTO Search,Print_data,Compute,Plot_course,Print_log,Quit
500   !
510   !
520   ! ROUTINE TO PRINT DATA BEGINS HERE...........
530   !
540   !
550 Print_data:      PRINTER IS 16
560   PRINT PAGE
570   ON END #1 GOTO End_file
571   INPUT "Do you want to see raw data?(Y/N)",Data$
572   INPUT "Do you want hard copy?(Y/N)",Prin$
580 Ent_waypt:    INPUT "Which waypoint number is the data in?",Waypoint
590   IF Waypoint<1 THEN GOTO Way_err
600 Which_way:      IF Waypoint=Way_no THEN GOTO Read_data
610   IF Waypoint>Way_no THEN GOTO Forward
620   IF Waypoint<Way_no THEN GOTO Backward
630   !
```

```
640 Read_data:       ! READING OF DATA OCCURS HERE.
650   ON ERROR GOTO Bad_file
660   GOSUB Read_waypt
670   OFF ERROR
680   PRINTER IS 0
690   PRINT LIN(3),"Waypoint #";Waypoint
700   PRINT "For this leg of the run, the vehicle began to move at ";Strings$(1)
710   PRINT "This waypoint logged at ";Strings$(3)
720   PRINT "Waypoint description:",LIN(1),TAB(10),Strings$(2)
730   PRINT "# of recorded data points for this leg of journey =";Nnn
740 N_points:    INPUT "Which data points do you want printed (start, end)?",Sta
rt,Finish
750   PRINTER IS 16
760   IF Start>Finish THEN PRINT CHR$(7),"WHAT??? Try again....."
770   IF Start>Finish THEN GOTO N_points
780   PRINT PAGE
790   PRINTER IS 0
791   IF Prin$="N" THEN PRINTER IS 16
800   IF Finish>Nnn THEN Finish=Nnn
810   PRINT LIN(1),D$&"Point #"&A$;SPA(15),D$&"X"&A$;SPA(19),D$&"Y"&A$;SPA(18),D
$&"Theta"&A$,LIN(1)
820   FOR I=Start TO Finish
821   IF Data$="Y" THEN GOTO Raw
830   PRINT I,X(I),Y(I),Theta(I)
831   GOTO After
832 Raw:  !
833   PRINT I,A(I),B(I),Theta(I)
834 After: !
840   NEXT I
850   IF Finish=Nnn THEN PRINT "NO MORE DATA IN THIS WAYPOINT."
860   PRINT LIN(1)
870   INPUT "Want to print more data from this waypoint (Y/N)?",Dummy$
880   IF Dummy$="Y" THEN GOTO N_points
890   INPUT "Want to print data from another waypoint (Y/N)?",Dummy$
900   IF Dummy$="Y" THEN GOTO Ent_waypt
910   GOTO Avail_routines
920 Forward:      ! NEED TO SPACE FORWARD TO DESIRED WAYPOINT ON TAPE.
930   Way_no=Way_no+1
940   IF Waypoint=Way_no THEN GOTO Read_data
950   ON ERROR GOTO Bad_file
960   GOSUB Read_waypt
970   OFF ERROR
980   GOTO Forward
990   !
1000 Backward:  !    NEED TO GO BACKWARD IN FILE.
1010  ! CLOSE THE RE-OPEN FILE TO START FROM BEGINNING.
1020  ASSIGN * TO #1
1030  ASSIGN F_name$&":T14" TO #1
1040  !  READ HEADER TO POSITION TAPE TP FIRST WAYPOINT.
1050  ON ERROR GOTO Bad_file
1060  GOSUB Read_heading
1070  OFF ERROR
1080  Way_no=1
1090  GOTO Which_way
1100  !
1110  !
1120  ! ROUTINE TO COMPUTE DISTANCES TRAVELLED STARTS HERE.
1130  !
1140  !
1150 Compute: PRINTER IS 0
1160  ASSIGN * TO #1
1170  ASSIGN F_name$&":T14" TO #1
1180  ON ERROR GOTO Bad_file
1190  ON END #1 GOTO Eof
1200  GOSUB Read_heading
1210  OFF ERROR
```

```
1220  PRINT LIN(2),D$&"Way pt.#"&A$;SPA(5),D$&"Waypoint description"&A$;SPA(5),D
$&"Way pt. dist. (M)"&A$;SPA(5),D$&"Cumm. dist."&A$
1230  PRINT
1240  Way_no=0
1250  Total_dist=0
1260 Read_it:    ! LOOP TO READ AND PRINT DATA BEGINS HERE.
1270  ON ERROR GOTO Bad_file
1280  GOSUB Read_waypt
1290  OFF ERROR
1300  Way_no=Way_no+1
1310  PRINTER IS 16
1320  PRINT PAGE,CHR$(27)&"&dA"&"          BUSY COMPUTING"
1330  GOSUB Comp_dist       ! ROUTINE TO COMPUTE DISTANCE TRAVELLED
1340  PRINT PAGE
1350  PRINTER IS 0
1360  Total_dist=Total_dist+Way_dist
1370  ! SEPARATE WAYPOINT DESCRIPTION INTO SMALLER STRINGS FOR PRINTING.
1380  GOSUB Segment
1390  PRINT SPA(2);Way_no;TAB(18),Half1$;TAB(40),Way_dist;TAB(59),Total_dist
1400  IF LEN(Half2$)>0 THEN PRINT TAB(15),Half2$
1410  IF LEN(Half3$)>0 THEN PRINT TAB(15),Half3$
1420  GOTO Read_it
1430 Eof:     ! END OF FILE FOR 'COMPUTE' ROUTINE HANDLED HERE.
1440  IF Way_no=0 THEN GOTO Bad_file         ! CHECK FOR BAD FILE.
1450  PRINT LIN(1),"Total # of waypoints =";Way_no
1460  PRINT "Total distance travelled =";Total_dist,LIN(1)
1470  GOTO Avail_routines
1480  !
1490  ! ROUTINE TO PRINT RUN LOG STARTS HERE.
1500  !
1510 Print_log:              ! FIRST GET TO BEGINNING OF FILE.
1520  ASSIGN * TO #1
1530  ASSIGN F_name$&":T14" TO #1
1540  BUFFER #1
1550  PRINTER IS 0
1560  PRINT LIN(3),SPA(5),E$&"DTIME",SPA(11),"WHAT HAPPENED",SPA(18),"OPERATOR I
NPUTS"&E$&"A"
1570  PRINT
1580  ON ERROR GOTO Bad_file
1590  ON END #1 GOTO Bad_file
1600  GOSUB Read_heading
1610  PRINT Strings$(1);TAB(18),"HEADER ENTRY";TAB(47),"(SEE ABOVE)"
1620  ON END #1 GOTO Home
1630  Way_no=0
1640 Read_loop: GOSUB Read_waypt
1650  Way_no=Way_no+1
1660  GOSUB Segment
1670  PRINT Strings$(1);TAB(18),"VEHICLE STARTED MOVING"
1680  PRINT Strings$(3);TAB(18),"WAY POINT STOP #";Way_no;TAB(47),Half$
1690  IF LEN(Half2$)>0 THEN PRINT TAB(47),Half2$
1700  IF LEN(Half3$)>0 THEN PRINT TAB(47),Half3$
1710  GOTO Read_loop
1720 Home: Strings$(2)=Strings$(1)
1730  GOSUB Segment
1740  PRINT Strings$(3);TAB(18),"END OF RUN";TAB(47),Half1$
1750  IF LEN(Half2$)>0 THEN PRINT TAB(47),Half2$
1760  IF LEN(Half3$)>0 THEN PRINT TAB(47),Half3$
1770  GOTO Avail_routines
1780  !
1790 Plot_course:            ! ROUTINE TO PLOT COURSE ON GRAPHICS SCREEN.
1800  PRINT PAGE,"ENTER MINIMUM AND MAXIMUM VALUES FOR X AXIS (IN KM):"
1810  INPUT Xp_min,Xpmax
1820  PRINT "ENTER MINIMUM AND MAXIMUM VALUES FOR Y AXIS (IN KM):"
1830  INPUT Yp_min,Yp_max
1840  Plot_min=MIN(Xp_min,Yp_min)
1850  Plot_max=MAX(Xp_max,Yp_max)
```

```
1860  Minor=.1
1870  ! CALCULATE MAJOR AND MINOR TIC INCREMENTS.
1880  Delt=Plot_max-Plot_min
1890  IF Delt/Minor>40 THEN Minor=.2
1900  IF Delt/Minor>40 THEN Minor=.5
1910  IF Delt/Minor>40 THEN Minor=1
1920  IF Delt/Minor>40 THEN Minor=2
1930  IF Delt/Minor>40 THEN Minor=5
1940  IF Delt/Minor>40 THEN Minor=10
1950  Dummy$=VAL$(10*Minor)
1960  Dummy$=Dummy$[1;1]
1970  Digit=VAL(Dummy$)
1980  Major=5
1990  IF Digit=5 THEN Major=4
2000  PLOTTER-IS 13,"GRAPHICS"
2010  GRAPHICS
2020  LOCATE 0,123,0,100
2030  SHOW Plot_min,Plot_max,Plot_min,Plot_max
2040  AXES Minor,Minor,0,0,Major,Major
2050  GOSUB Label
2060  ! CLOSE THEN RE-OPEN FILE TO START AT BEGINNING.
2070  ASSIGN * TO #1
2080  ASSIGN F_name$&":T14" TO #1
2090  ON ERROR GOTO Bad_file
2100  OFF END #1
2110  GOSUB Read_heading
2120  OFF ERROR
2130  Way_no=0
2140  ON END #1 GOTO Done
2150  MOVE 0,0
2160  GOSUB Read_waypt
2170  Xn=X(1)
2180  Yn=Y(1)
2190  Xplot=0
2200  Yplot=0
2210 Plot_it:!
2220  Del_x=Delt
2230  Delt=Y(1)-Yn
2240  FOR K=2 TO Nnn
2250  Delt=X(K)-X(K-1)
2260  Del_x=Delt
2270  Delt=Y(K)-Y(K-1)
2280  Yplot=Y(K)*Scale/1000
2290  Xplot=X(K)*Scale/1000
2300  PLOT Xplot,Yplot,-1
2310  NEXT K
2320  GOSUB Read_waypt
2330  GOTO Plot_it
2340 Done: DUMP GRAPHICS
2350  GOTO Avail_routines
2360  !
2370  !
2380  !
2390  ! SUBROUTINES TO DO THE WORK.
2400  !
2410  !
2420 Label:      ! SUBROUTINE TO LABEL TI MARKS.
2430  Dl=Major*Minor
2440  Ypos=-(Plot_max-Plot_min)/50
2450  Xpos=Ypos
2460  CSIZE 3
2470  ! LABEL POSITIVE X AND Y AXES....
2480  FOR K=Dl TO Plot_max STEP Dl
2490  LORG 6
2500  MOVE K,Ypos
2510  LABEL K
```

```
2520  LORG 8
2530  MOVE Xpos,K
2540  LABEL K
2550  NEXT K
2560  ! LABEL NEGATIVE X, Y AXES.
2570  FOR K=D1 TO ABS(Plot_min) STEP D1
2580  LORG 6
2590  MOVE -K,Ypos
2600  LABEL -K
2610  LORG 8
2620  MOVE Xpos,-K
2630  LABEL -K
2640  NEXT K
2650  RETURN
2660  !
2670  !
2680 Read_heading:      ! SUBROUTINE TO READ THE HEADER.
2690  ! WARNING: TAPE MUST BE AT THE BEGINNING OF THE FILE AND
2700  ! HAVE BEEN ASSIGNED TO FILE #1
2710  FOR Trace=1 TO 6
2720  READ #1;Strings$(Trace)
2730  NEXT Trace
2740  RETURN
2750  !
2760  !
2770 Read_waypt:        ! SUBROUTINE TO READ WAYPOINT DATA.
2780  ! WARNING: TAPR MUST BE POSITIONED TO THE BEGINNING OF A WAYPOINT
2790  ! AND MUST BE ASSIGNED TO FILE #1.
2800  READ #1;Strings$(1)
2810  READ #1;Strings$(2)
2820  READ #1;Strings$(3)
2830  X1=X(1)
2840  X2=X(2)
2850  Xn=X(Nnn)
2860  Yn=Y(Nnn)
2870  READ #1;Nnn
2880  REDIM A(Nnn),B(Nnn),Theta(Nnn)
2890  READ #1;A(*)
2900  READ #1;B(*)
2910  READ #1;Theta(*)
2920  GOSUB Rollover
2930  RETURN
2940  !
2950  !
2960 Comp_dist:       ! SUBROUTINE TO COMPUTE DISTANCES TRAVELLED
2970                  ! BETWEEN WAY POINTS.
2980  Way_dist=0
2990  IF Way_no<>1 THEN GOTO Not1    ! FIRST WAY POINT?
3000  Xn=X(1)          ! YES. SET INITIAL CONDITIONS.
3010  Yn=Y(1)
3020  Xcum=0
3030  Ycum=0
3040  Xmax=0
3050  Ymax=0
3060  Xmin=0
3070  Ymin=0
3080 Not1:              ! Xn AND Yn ARE CARRYOVER FROM LAST WAT POINT.
3090  ! Del_x=(X(1)-Xn)*Scale
3100  ! Del_y=(Y(1)-Yn)*Scale
3110  ! Way_dist=Way_dist+SQR(Del_x^2+Del_y^2)
3120  Xcum=Xcum+Del_x
3130  Ycum=Ycum+Del_y
3140  Xmax=MAX(Xmax,Xcum)
3150  Xmin=MIN(Xmin,Xcum)
3160  Ymax=MAX(Ymax,Ycum)
3170  Ymin=MIN(Ymin,Ycum)
```

```
3180  FOR K=2 TO Nnn
3190  Del_x=(X(K)-X(K-1))*Scale
3200  Del_y=(Y(K)-Y(K-1))*Scale
3210  Way_dist=Way_dist+SQR(Del_x^2+Del_y^2)
3220  NEXT K
3230  RETURN
3240  !
3250  !
3260 Segment:              ! ROUTINE TO SEGMENT AN 80 CHARACTER STRING
3270                       ! INTO 3 STRINGS.
3280  Half1$=""
3290  Half2$=""
3300  Half3$=""
3310  Half1$=Strings$(2)[1;30]
3320  IF LEN(Half1$)=30 THEN Half2$=Strings$(2)[31;30]
3330  IF LEN(Half2$)=30 THEN Half3$=Strings$(2)[61,80]
3340  RETURN
3350  !
3360  !
3370 Bad_file:   ! ROUTINE TO HANDLE ERRORS IN THE FILE READING ROUTINES.
3380  PRINTER IS 0
3390  PRINT LIN(3),"FATAL ERROR IN FILE HANDLING ROUTINE."
3400  PRINT ERRM$;"; TRACE = ";Trace
3410  GOTO Quit
3420  !
3430  !
3440 End_file:   ! ROUTINE TO HANDLE UNEXPECTED END-OF-FILE.
3450  PRINTER IS 0
3460  PRINT LIN(3),"END-OF-FILE ENCOUNTERED. PROGRAM HALTED. TRACE= ";Trace
3470 Quit: PRINTER IS 16        ! NORMAL PROGRAM ENDING.
3480  PRINT "END OF PROGRAM 'REDUCE'."
3490  STOP
3500 Rollover:!  CHANGES FROM MODULO TO ABSOLUTE.
3510  IF Way_no=1 THEN Xplus=Yplus=0
3520  X(1)=A(1)+Xplus
3530  Y(1)=B(1)+Yplus
3540  FOR N=2 TO Nnn
3541  IF (B(N)-B(N-1)<-500) AND (B(N)-B(N-1))-60000) THEN B(N)=B(N-1)
3542  IF (B(N)-B(N-1)>500) AND (B(N)-B(N-1)<60000) THEN B(N)=B(N-1)
3550  IF A(N)-A(N-1)>60000 THEN Xplus=Xplus-65536
3560  IF B(N)-B(N-1)>60000 THEN Yplus=Yplus-65536
3570  IF A(N)-A(N-1)<-60000 THEN Xplus=Xplus+65536
3580  IF B(N)-B(N-1)<-60000 THEN Yplus=Yplus+65536
3590  X(N)=A(N)+Xplus
3600  Y(N)=B(N)+Yplus
3610  NEXT N
3620  RETURN
3630  END
```

File name:
TEST13
TEST DATE:
10 MAY 83
Test description:
LONG TEST #9 CW
Comments:
NFM=6358.7
Route description:

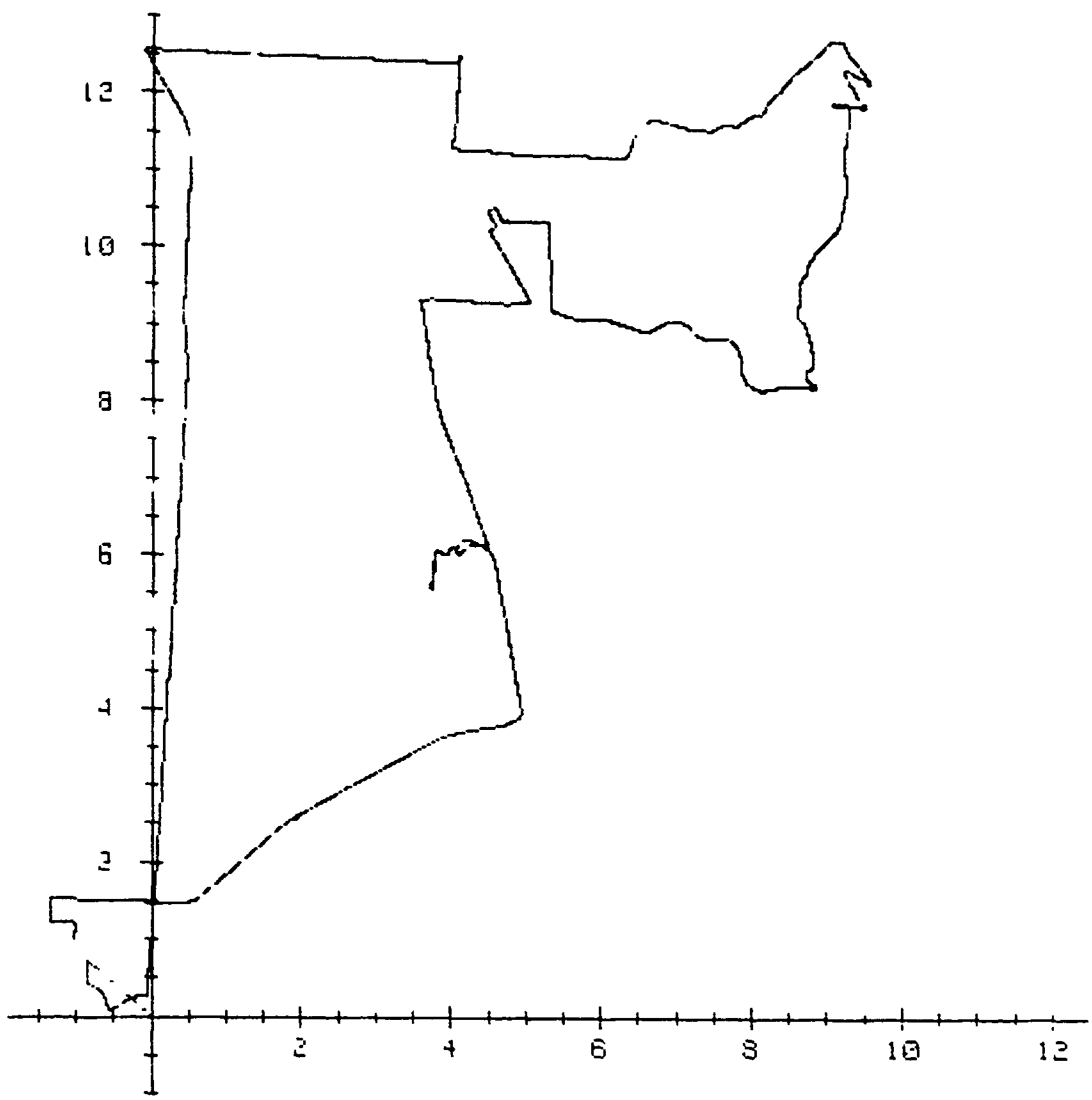
Starting location:
RSA
Test start time:
05:10:13:51:54

Waypoint # 1
For this leg of the run, the vehicle began to move at 05:10:13:52:27
This waypoint logged at 05:10:14:01:42
Waypoint description:
GC13 C=5028
# of recorded data points for this leg of journey = 790

Point #	X	Y	Theta
1	-17693	14830	16236
2	-17686	15027	15498
3	-17547	15186	2070
4	-17386	15091	-10319
5	-17348	14867	-16551
6	-17360	14670	-17080
7	-17373	14473	-17121
8	-17389	14243	-17071
9	-17400	14046	-16903
10	-17408	13848	-16753
11	-17417	13618	-16787
12	-17425	13421	-16868
13	-17437	13190	-16988
14	-17449	12993	-17022
15	-17462	12796	-17049

Way pt.#	Waypoint description	Way pt. dist. (M)	Cumm. dist.
1	GC13 C=5028	8004.968894	8004.968894
2	GC11 C=6332	10076.1952338	18081.1641278
3	GC10 C=5825	9272.99125084	27354.1553786
4	CHURCH C=6566	10448.8596187	37803.0149973
5	GC1A C=4725	7516.97981652	45319.9948138
6	GC13 C=4375	6962.29347314	52282.2882869
7	RSA C=2936	4664.68215953	56946.9704464

Total # of waypoints = 7
Total distance travelled = 56946.9704464



Example of the recreations of runs
"REDUCE" can perform.

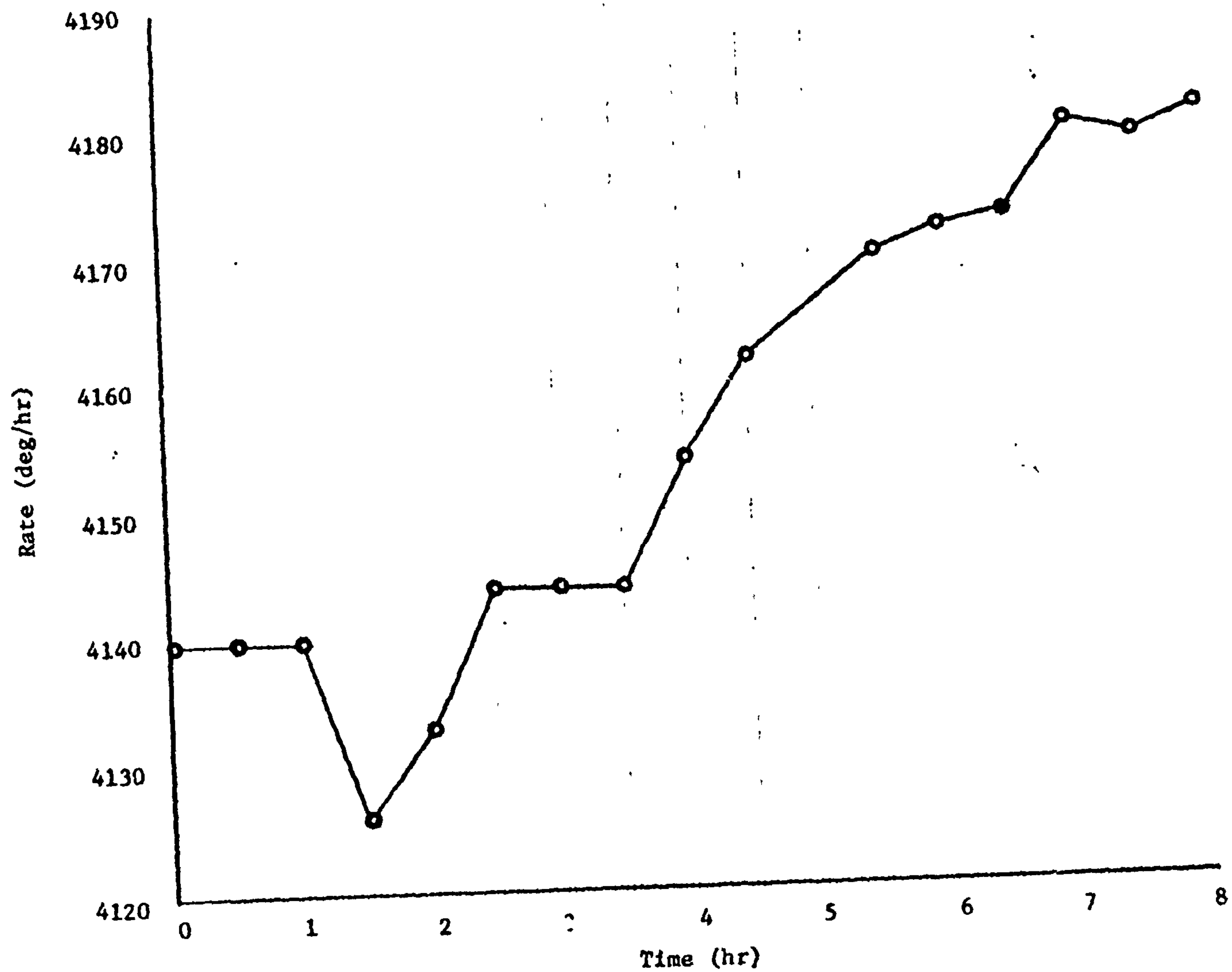


Figure F-1. Static drift.

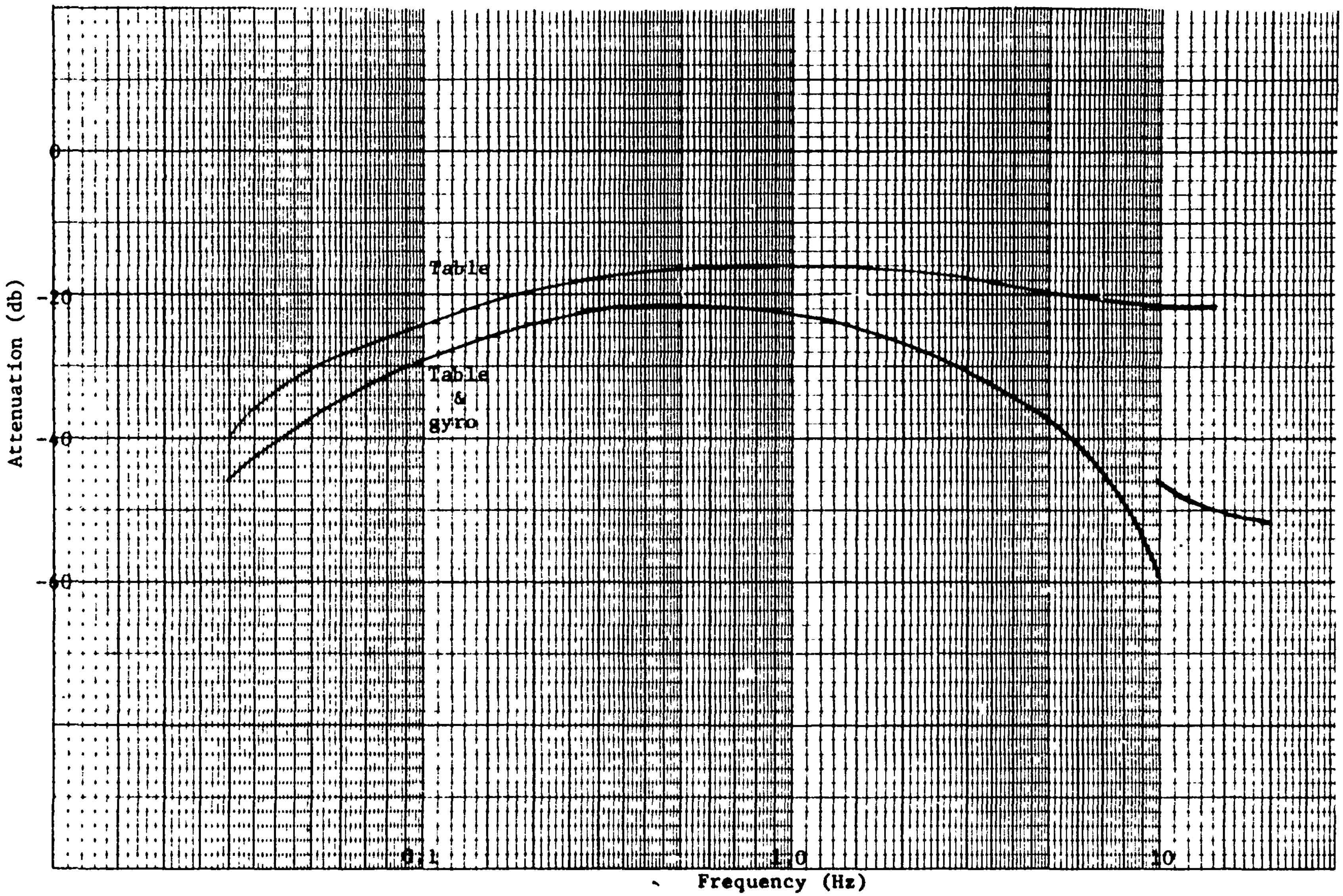


Figure F-2. Frequency response.

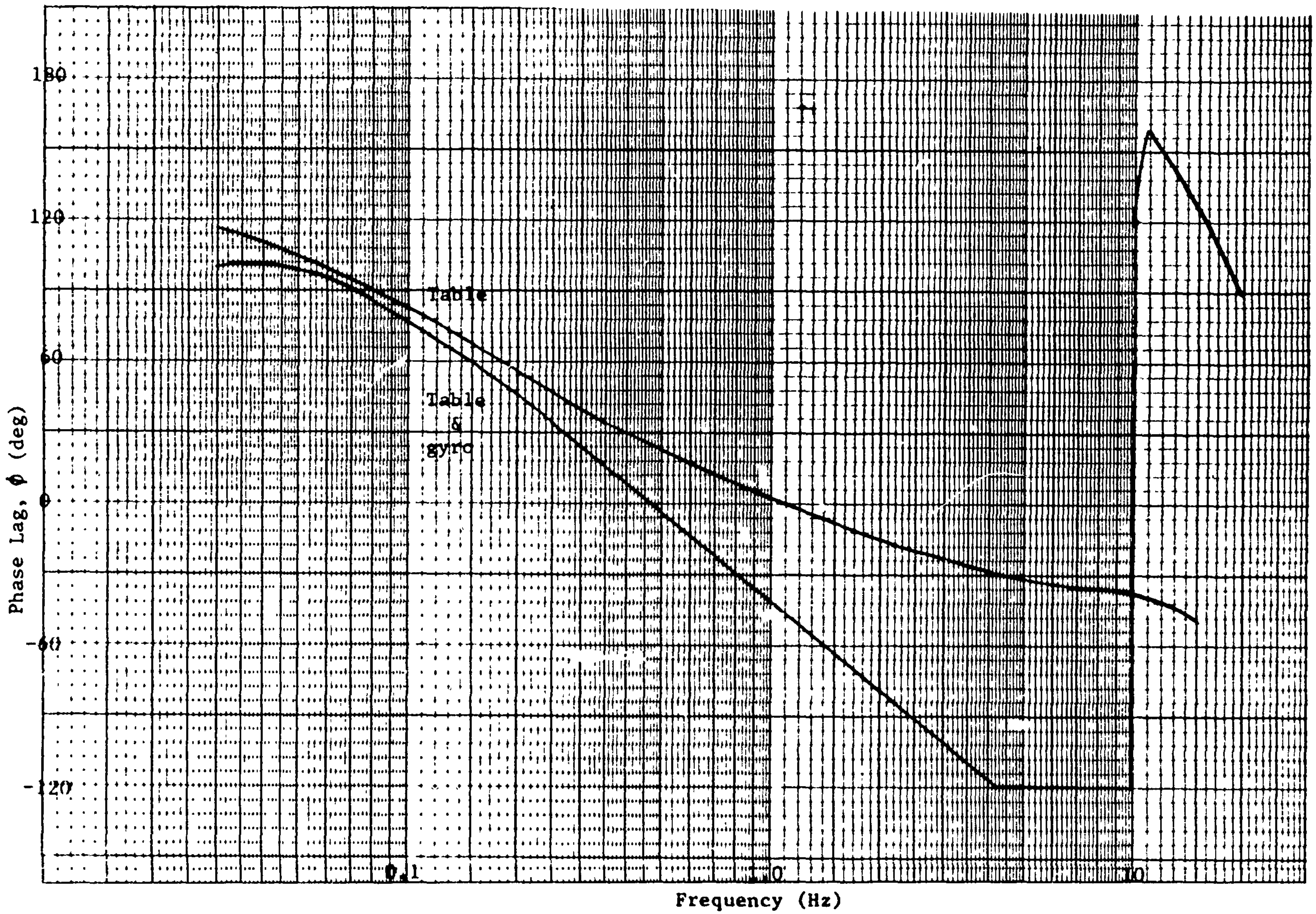


Figure F-3. Phase lag.

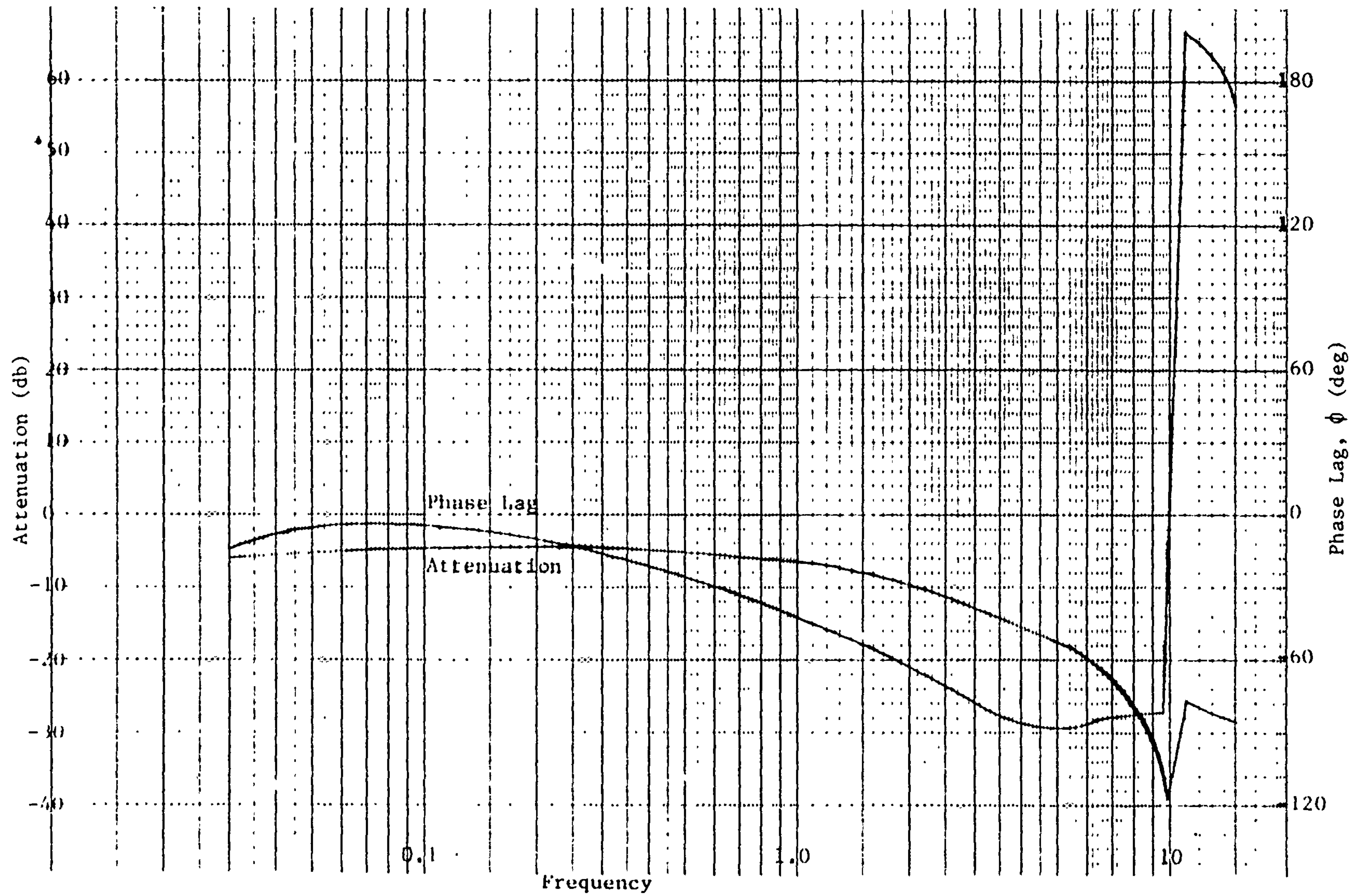


Figure F-4. "Electro Gyro-Cater" frequency response and phase lag.

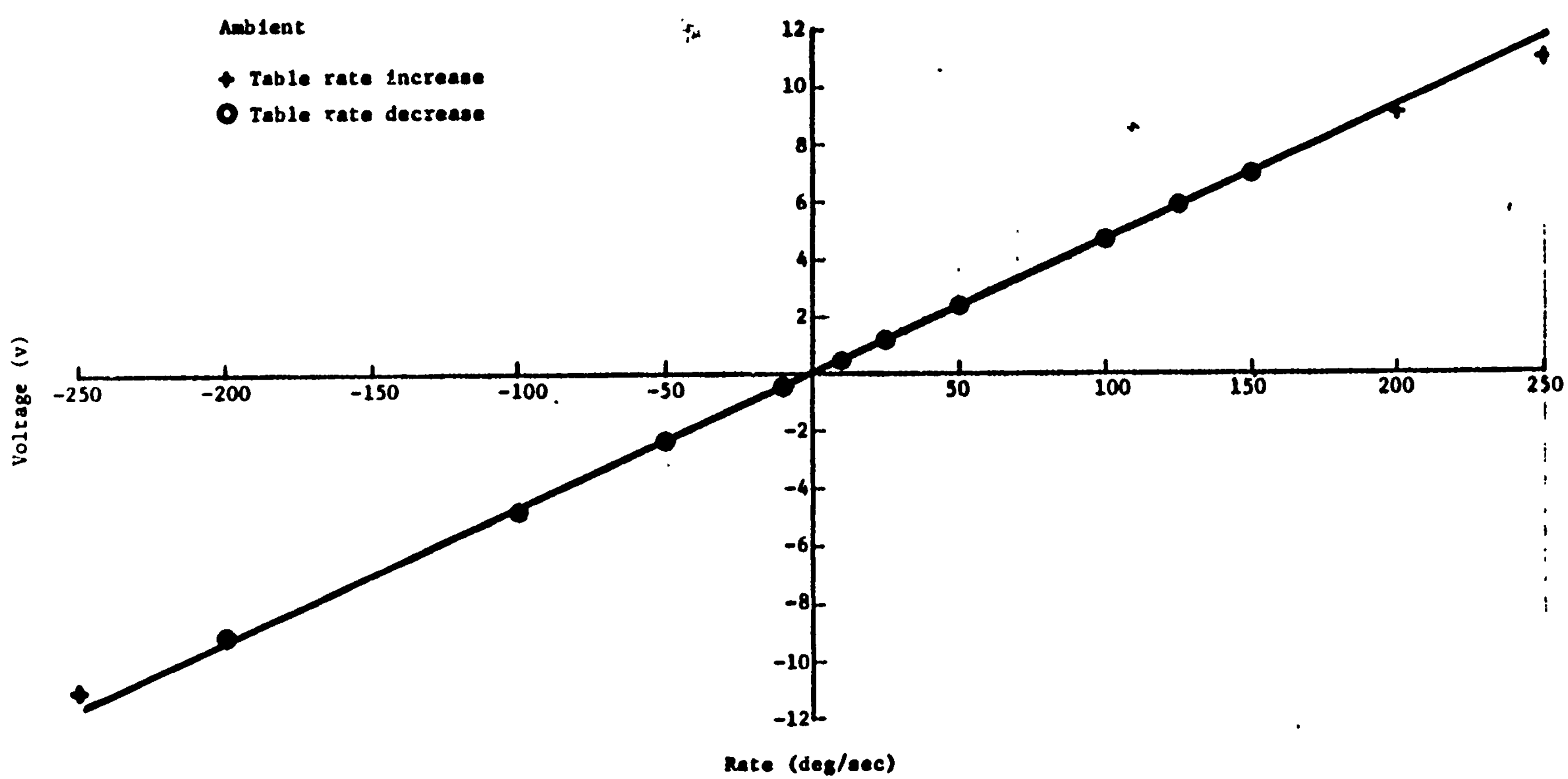


Figure F-5. Input-output characteristics.

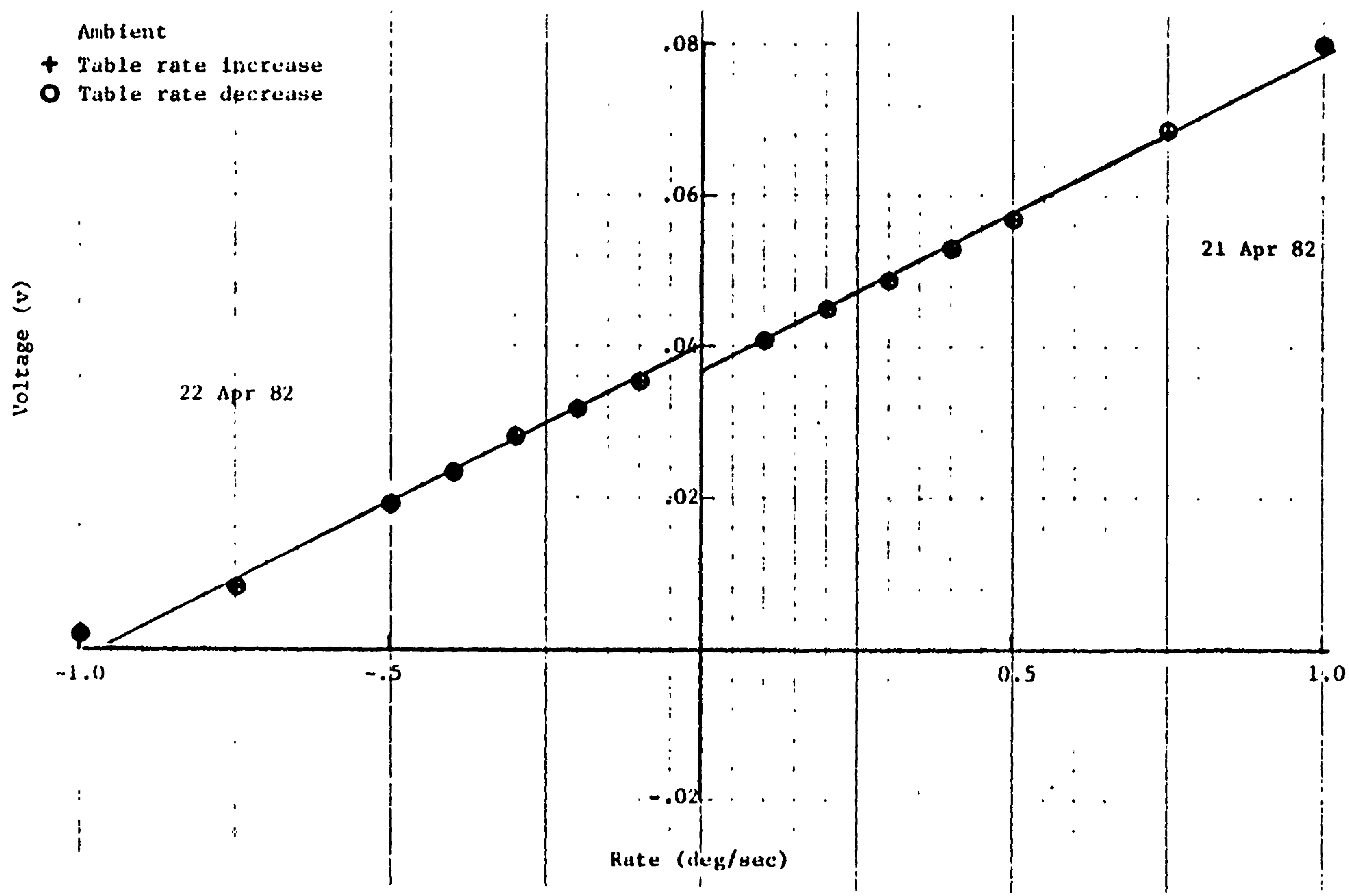


Figure F-6. Input-output characteristics.

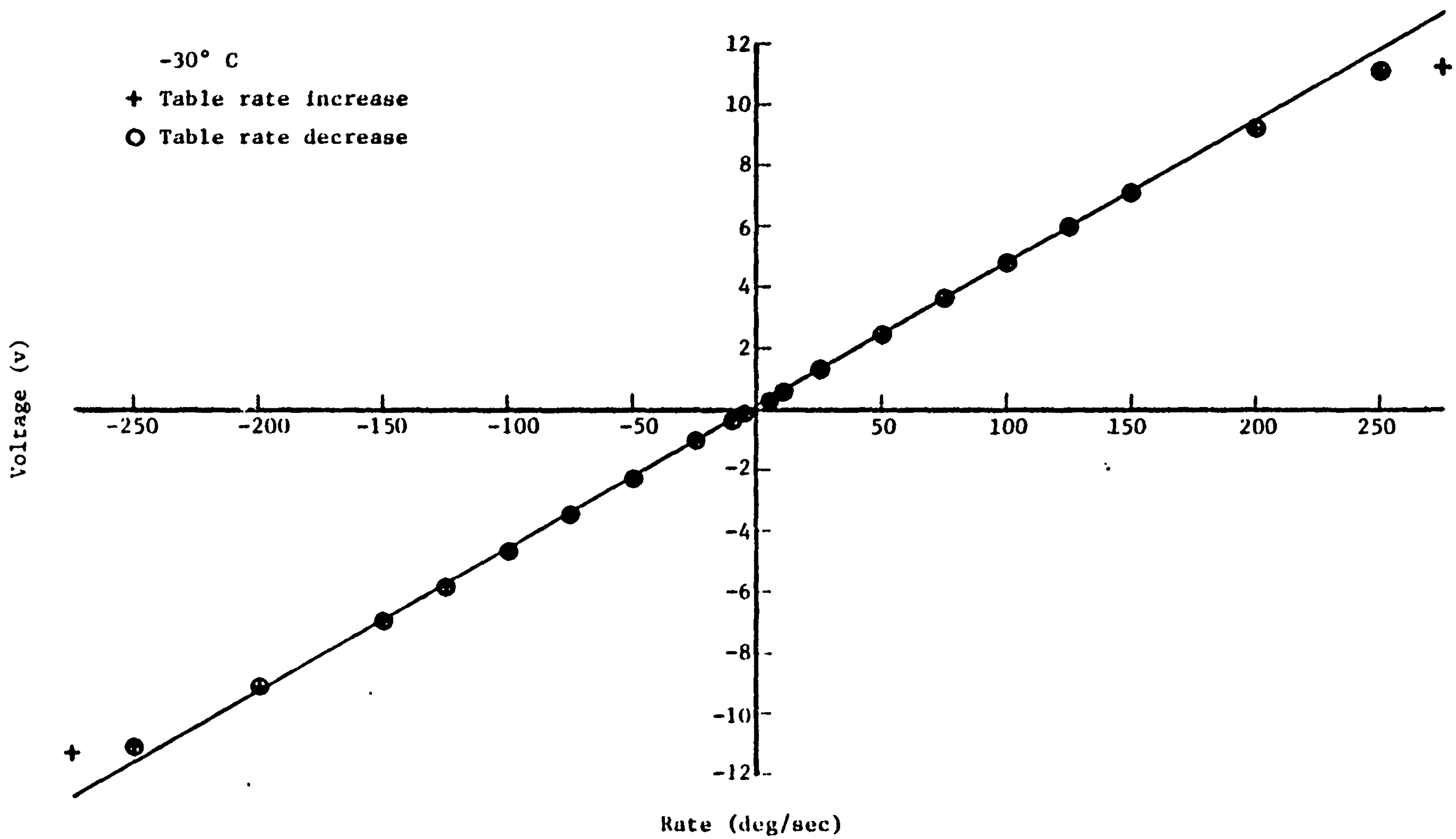


Figure F-7. Input-output characteristics.

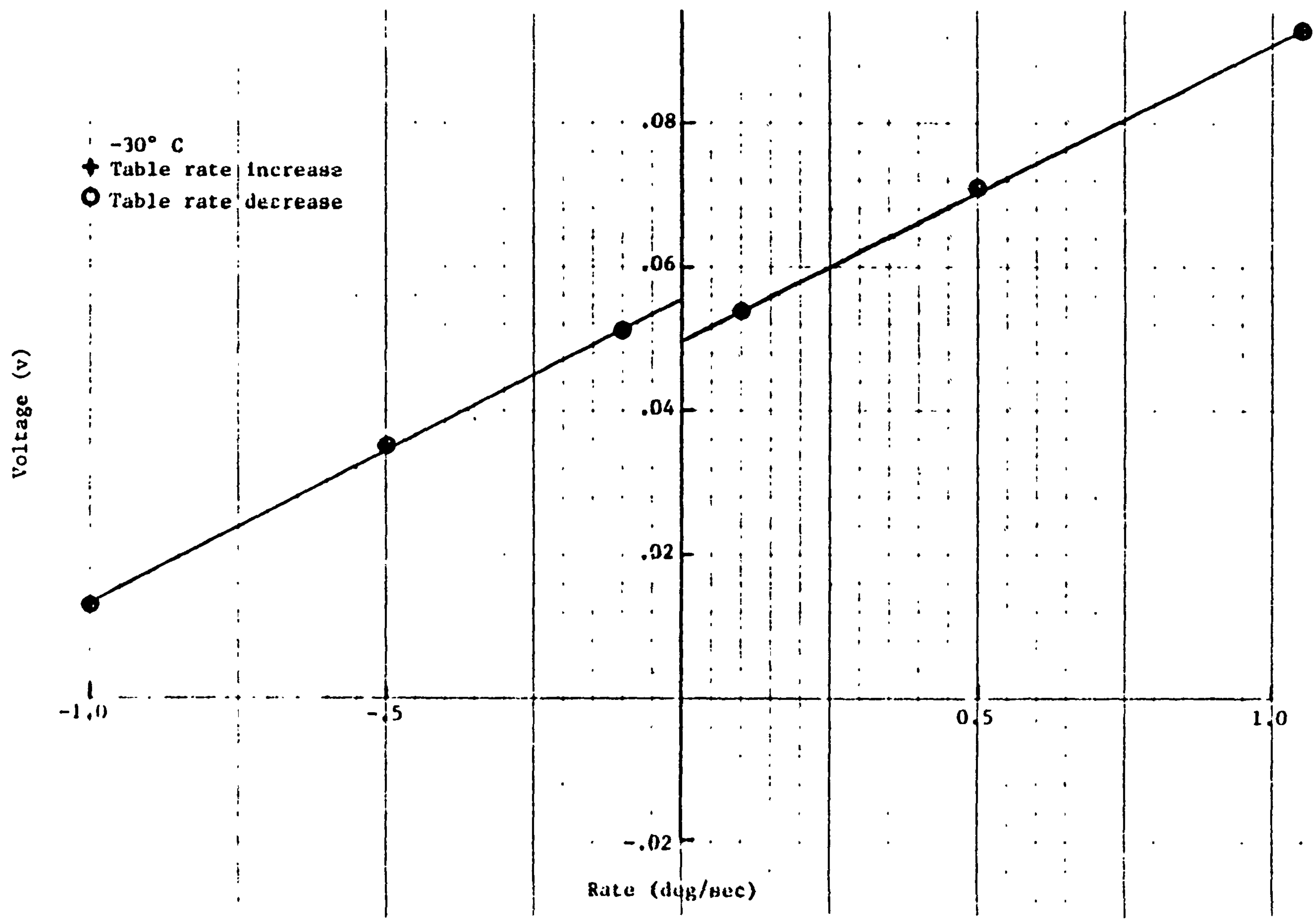


Figure F-8. Input-output characteristics.

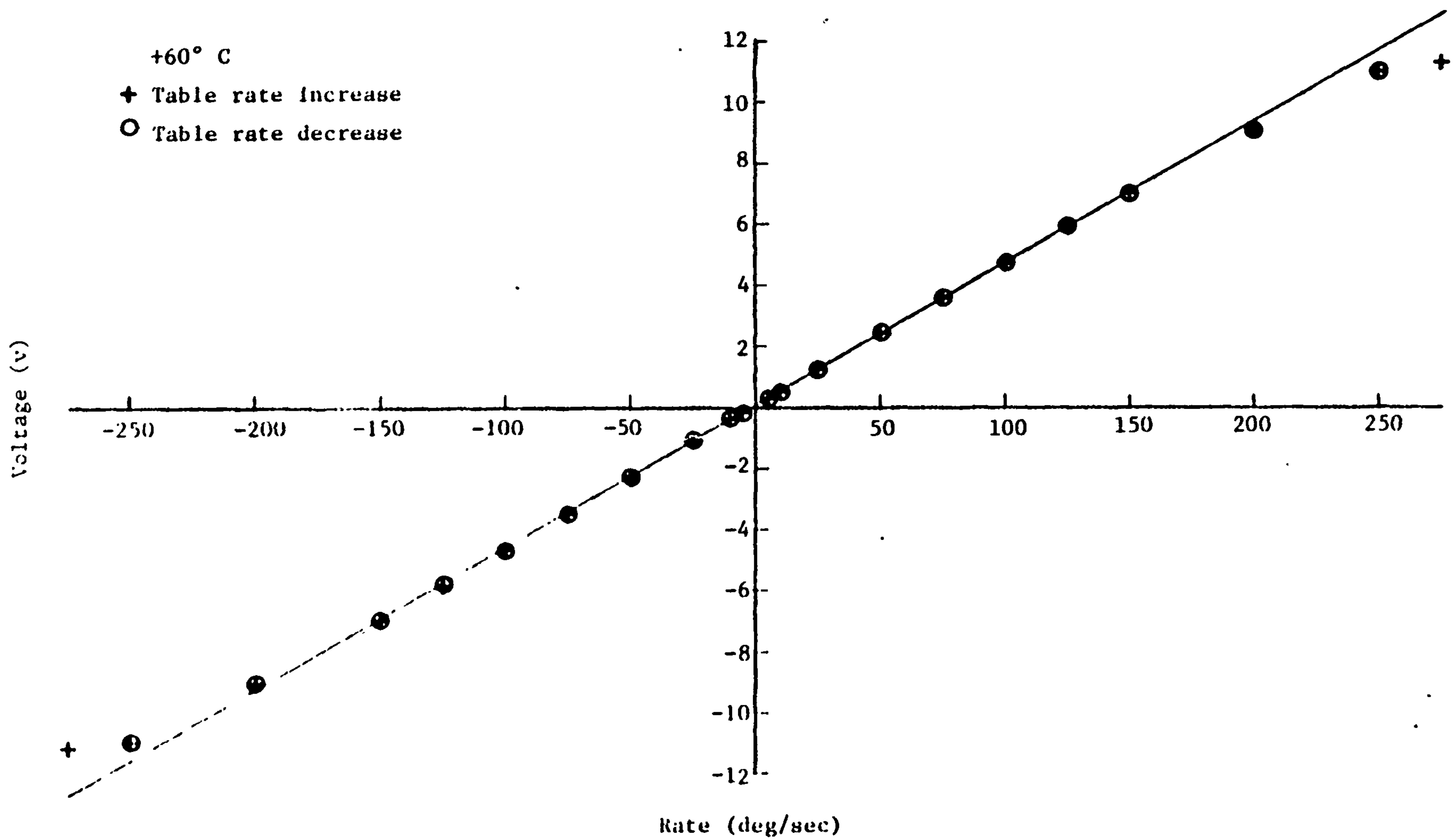


Figure F-9. Input-output characteristics.

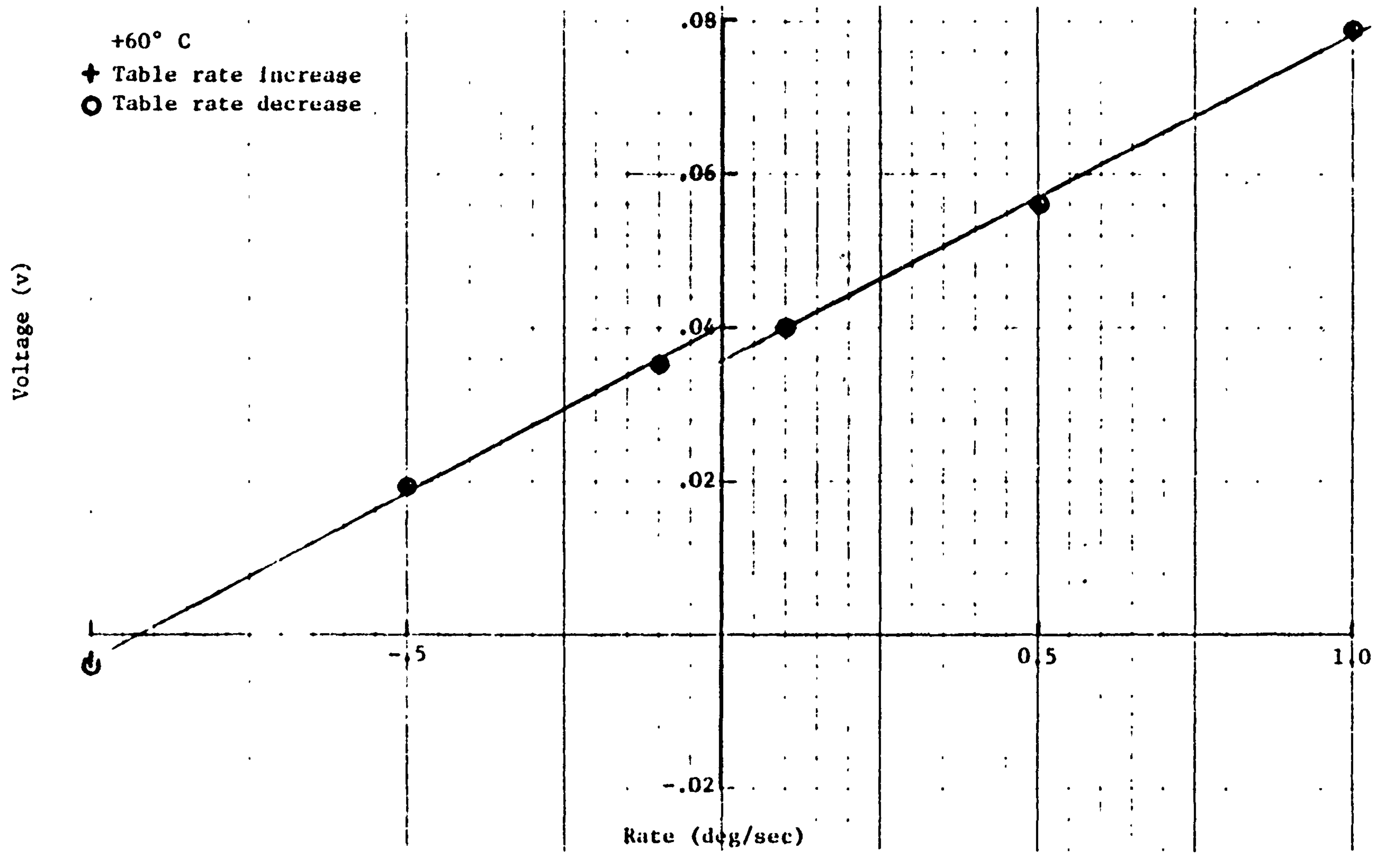


Figure F-10. Input-output characteristics.

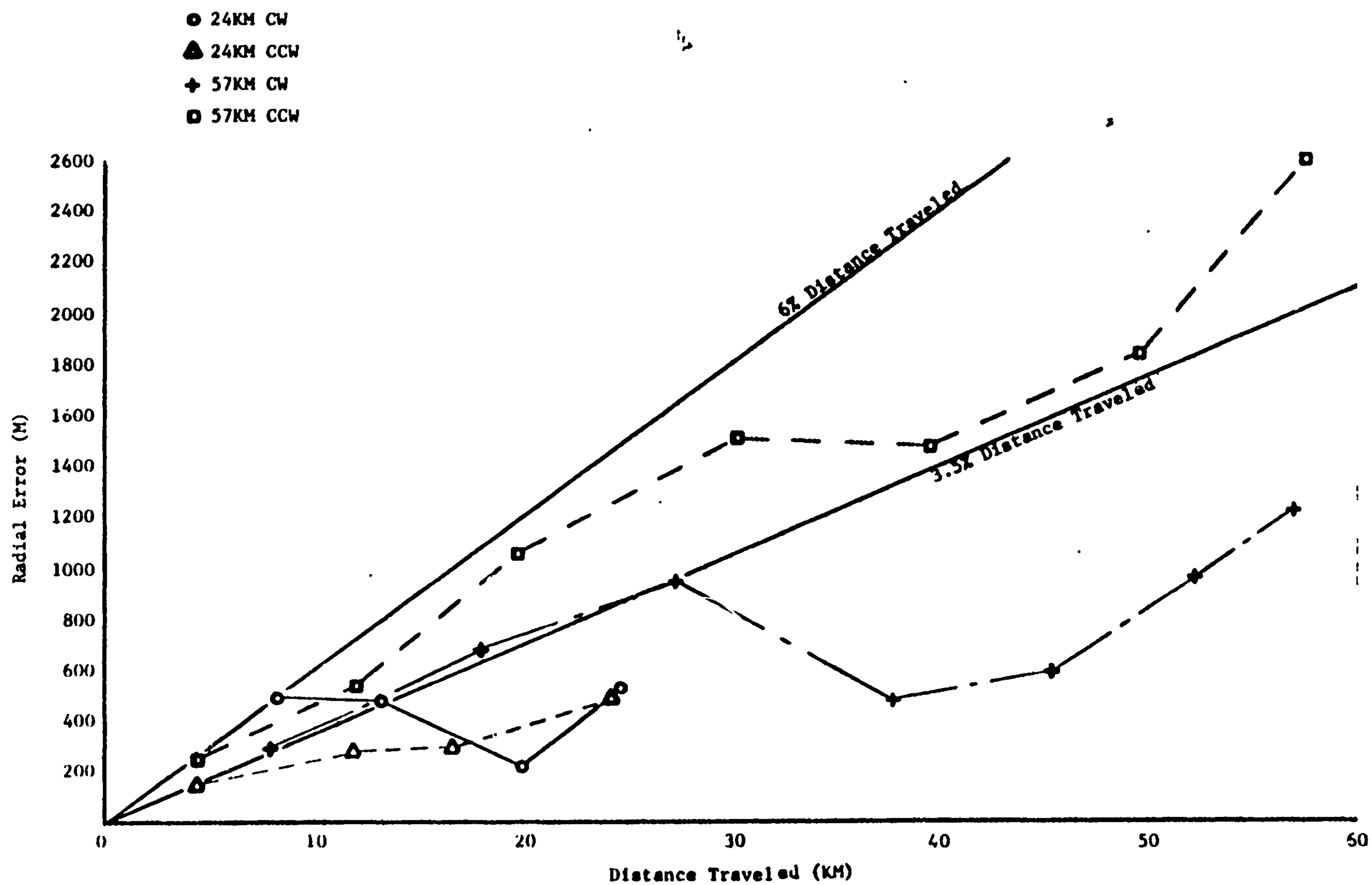


Figure F-11. Distance traveled vs RMS radial error.

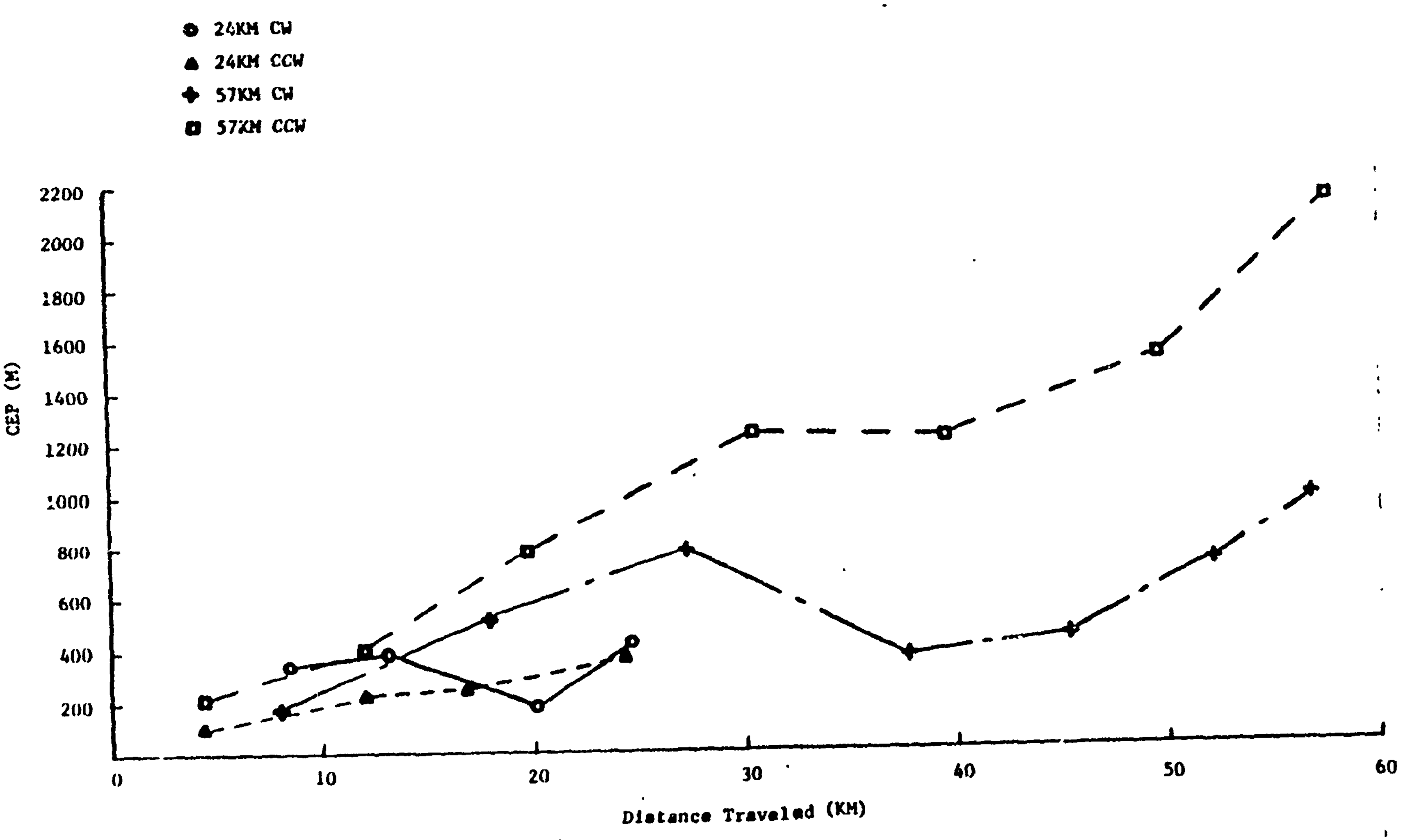


Figure F-12. Distance traveled vs CEP.

TABLE F-1. INPUT-OUTPUT CHARACTERISTICS

TEMERATURE	SCALE FACTOR		VOLTS	BIAS	
	Volts/deg/sec	Volts/deg/hr		deg/sec	deg/hr
ambient	0.0493	0.0000137	0.0358	0.7262	2614.32
-30°C	0.0492	0.0000137	0.0518	1.0528	3790.08
+60°C	0.0489	0.0000136	0.0375	0.7669	2760.84

TABLE F-2. RADIAL ERROR AND % ERROR FOR 24 KM COURSE, CW

Run No.	Radial Error (m)	% Error of Dist. Traveled
2.1	643.22	7.65
2.2	626.10	4.77
2.3	257.60	1.28
2*	955.74	3.86
4.1	367.78	4.37
4.2	376.37	2.64
4.3	181.29	0.90
4*	65.46	0.26
6.1	235.60	2.80
6.2	187.47	1.43
6.3	159.88	0.80
6*	501.88	2.03
8.1	270.93	3.22
8.2	285.27	2.17
8.3	126.40	0.63
8*	298.19	1.61
10.1	296.52	3.52
10.2	233.39	1.78
12.1	813.39	9.57
12.2	815.71	6.22
12.3	337.27	1.63
12*	178.20	0.72

*Closed loop, back to starting point

TABLE F-3. RADIAL ERROR AND % ERROR FOR 24 KM COURSE, CCW

Run No.	Radial Error (m)	% Error of Dist. Traveled
1.1	88.75	2.00
1.2	178.20	1.48
1.3	194.23	1.16
3.1	74.02	1.67
3.2	258.63	2.14
3.3	252.10	1.50
3*	159.84	0.66
5.1	156.21	3.52
5.2	360.35	2.98
5.3	299.87	1.79
5*	171.55	0.70
7.1	93.72	2.11
7.2	221.68	1.84
7.3	31.76	0.19
7*	428.60	1.76
9.1	155.16	3.49
9.2	399.74	3.31
9.3	447.00	2.66
9*	140.63	0.58
11.1	103.14	2.32
11.2	211.24	1.75
11.3	367.88	2.19
11*	966.60	3.97

*Closed loop, back to starting point.

TABLE F-4. RADIAL ERROR AND % ERROR FOR
57 KM COURSE, CCW

Run No.	Radial Error (m)	% Error of Dist. Traveled
1.1	139.23	3.14
1.2	333.32	2.76
1.3	706.64	3.57
1.4	1115.82	3.68
1.5	979.78	2.48
1.6	1111.31	2.24
1*	1450.30	2.52
2.1	237.19	5.34
2.2	485.80	4.02
2.3	796.56	4.03
2.4	1254.74	4.14
2.5	1129.63	2.86
2.6	904.29	1.82
2*	1612.65	2.80
3.1	107.37	2.42
3.2	171.07	1.42
3.3	181.70	0.92
3.4	169.72	0.56
3.5	843.71	2.14
3.6	2161.42	4.35
3*	3701.15	6.43
4.1	308.95	6.96
4.2	688.07	5.70
4.3	1167.71	5.91
4.4	1242.03	4.10
4.5	1665.44	4.22
4.6	2879.42	5.80
4*	3920.55	6.81
5.1	334.06	7.52
5.2	778.84	6.[illegible]5
5.3	1731.70	3.76
5.4	2653.29	8.75
5.5	2304.81	5.84
5.6	1412.15	2.84
5*	449.93	0.78

*Closed loop, back to starting point.

TABLE F-5. RADIAL ERROR AND % ERROR FOR 57 KM COURSE, CW

Run No.	Radial Error (m)	% Error of Dist. Traveled
6.1	449.77	5.61
6.2	1004.59	5.55
6.3	1215.68	4.44
6.4	772.71	2.04
6.5	77.90	0.17
6.6	529.87	1.01
6*	967.25	1.70
7.1	115.11	1.44
7.2	234.25	1.29
7.3	913.99	3.34
7.4	329.25	0.87
7.5	1174.69	2.59
7.6	1619.70	3.09
7*	1917.49	3.36
8.1	339.11	4.23
8.2	910.80	5.03
8.3	1261.72	4.60
8.4	458.01	1.21
8.5	526.96	1.16
8.6	1071.37	2.05
8*	1359.78	2.38
9.1	34.25	0.43
9.2	165.16	0.91
9.3	272.62	0.99
9.4	290.17	0.77
9.5	296.77	0.65
9.6	381.81	0.73
9*	351.25	0.62
10.1	254.93	3.18
10.2	556.90	3.07
10.3	708.01	2.58
10.4	426.83	1.13
10.5	161.86	0.36
10.6	652.04	1.24
10*	993.38	1.74

*Closed loop, back to starting point.

TABLE F-6. STATISTICS ON CCW 24 KM COURSE

From	To	Stat	ERROR Northing	Easting	Radial
RSA	GC13	RMS	67	95	116
		$\overline{X}$	7	88	112
		1σ	73	40	35
GC13	GC1A	RMS	167	229	283
		$\overline{X}$	114	166	272
		1σ	134	173	89
GC1A	GC1	RMS	181	235	296
		$\overline{X}$	62	75	266
		1σ	186	245	145
GC1	RSA	RMS	232	430	489
		$\overline{X}$	-78	278	374
		1s	244	366	352

TABLE F-7. STATISTICS ON CW 24 KM COURSE

From	To	Stat	ERROR Northing	Easting	Radial
RSA	GC1	RMS	117	473	488
		$\overline{X}$	101	338	438
		1σ	66	363	235
GC1	GC1A	RMS	276	385	474
		$\overline{X}$	-191	279	416
		1σ	262	291	250
GC1A	GC13	RMS	167	151	225
		$\overline{X}$	-21	-24	212
		1σ	185	167	54
GC13	RSA	RMS	400	334	522
		$\overline{X}$	308	-251	420
		1σ	286	247	346

TABLE F-8. STATISTICS ON CCW 57 KM COURSE

From	To	Stat	ERROR Northing	Easting	Radial
RSA	GC13	RMS	176	167	242
		$\bar{X}$	-153	161	225
		1σ	97	49	100
GC13	GC1A	RMS	214	496	[illegible]
		$\bar{X}$	-148	455	[illegible]91
		1σ	174	218	250
GC1A	Church	RMS	352	991	1052
		$\bar{X}$	-200	855	917
		1σ	324	560	576
Church	GC10	RMS	853	1249	1512
		$\bar{X}$	-657	1039	1287
		1σ	607	775	887
GC10	GC11	RMS	830	1232	1486
		$\bar{X}$	-623	964	1385
		1σ	613	858	601
GC11	GC1	RMS	1269	1339	1844
		$\bar{X}$	-668	1175	1693
		1σ	1206	717	815
GC1	RSA	RMS	1393	2203	2607
		$\bar{X}$	-719	1390	2227
		1σ	1334	1911	1515

TABLE F-9. STATISTICS ON CW 57 KM COURSE

From	To	Stat	ERROR Northing	ERROR Easting	ERROR Radial
RSA	GC1	RMS	17	281	282
		$\bar{X}$	-9	225	239
		1σ	16	188	167
GC1	GC11	RMS	285	604	668
		$\bar{X}$	-129	429	574
		1σ	284	475	382
GC11	GC10	RMS	734	598	947
		$\bar{X}$	-209	[illegible]	875
		1σ	787	[illegible]	406
GC10	Church	RMS	162	458	486
		$\bar{X}$	82	343	455
		1σ	157	340	190
Church	GC1A	RMS	198	562	596
		$\bar{X}$	178	103	448
		1σ	96	618	441
GC1A	GC13	RMS	342	899	962
		$\bar{X}$	319	100	851
		1σ	137	998	501
GC13	RSA	RMS	612	1068	1230
		$\bar{X}$	447	-141	1118
		1σ	466	1183	575

TABLE F-10. PERCENT RMS RADIAL ERROR PER DISTANCE TRAVELED

Course	Direction	From	To	Actual Distance (m)	Radial Error (m)	% Distance Traveled
24Km	CCW	RSA	GC13	4441	116	2.612
		GC13	GC1A	12079	283	2.335
		GC1A	GC1	16792	296	1.763
		GC1	RSA	24352	489	2.008
24Km	CW	RSA	GC1	8413	488	5.801
		GC1	GC1A	13116	474	3.614
		GC1A	GC13	20084	225	1.120
		GC13	RSA	24764	522	2.108
57Km	CCW	RSA	GC13	4441	242	5.449
		GC13	GC1A	12079	540	4.471
		GC1A	Church	19767	1052	5.322
		Church	GC10	30307	1512	4.989
		GC10	GC11	39487	1486	3.763
		GC11	GC1	49650	1844	3.714
		GC1	RSA	57559	2607	4.529
57	CW	RSA	GC1	8017	282	3.518
		GC1	GC11	18117	668	3.687
		GC11	GC10	27405	947	3.456
		GC10	Church	37874	486	1.283
		Church	GC1A	45408	596	1.313
		GC1A	GC13	52376	962	1.837
		GC13	RSA	57056	1230	2.156

TABLE F-11. CEP

Course	Direction	From	To	Actual Distance (m)	RMS ERROR Northing (m)	RMS ERROR Easting (m)	RMS ERROR CEP (m)
24Km	CCW	RSA	GC13	4441	67	95	95
		GC13	GC1A	12079	167	229	233
		GC1A	GC1	16792	181	235	245
		GC1	RSA	24352	232	430	390
24Km	CW	RSA	GC1	8413	117	473	348
		GC1	GC1A	13116	276	385	389
		GC1A	GC13	20084	167	151	187
		GC13	RSA	24764	400	334	432
57Km	CCW	RSA	GC13	4441	176	167	202
		GC13	GC1A	12079	214	496	418
		GC1A	Church	19767	352	991	791
		Church	GC10	30307	853	1249	1238
		GC10	GC11	39487	830	1232	1215
		GC11	GC1	49650	1269	1339	1536
		GC1	RSA	57559	1393	2203	2118
57	CW	RSA	GC1	8017	17	281	168
		GC1	GC11	18117	285	604	524
		GC11	GC10	27405	734	598	785
		GC10	Church	37874	162	458	365
		Church	GC1A	45408	198	562	448
		GC1A	GC13	52376	342	899	731
		GC13	RSA	57056	612	1068	990

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